Strategic and Critical Materials 2013 Report on Stockpile Requirements

Office of the Under Secretary of Defense for Acquisition, Technology and Logistics

January 2013

Preparation of this report/study cost the Department of Defense
a total of approximately $806,000 in Fiscal Years 2011 - 2012.
Cost estimate generated on September 13, 2012 RefID: 2-9B1D9E6

Contents

Strategic and Critical Materials 2013 Report on Stockpile Requirements

Overview

Pursuant to section 14 of the Strategic and Critical Materials Stock Piling Act, this report contains the Department of Defense (DoD) assessment of potential U.S. problems regarding strategic and critical non-fuel materials in the context of a congressionally-mandated Base Case planning scenario. The report recommends material-specific mitigation strategies for the problematic materials. Both essential defense and civilian demand for 76 materials are estimated in this Base Case and then compared against projected supplies of these materials that are judged by the intelligence community, along with inputs from DoD, the Department of the Interior, and industry, to be available from U.S. and foreign sources in this case. DoD finds shortfalls—insufficient supply to meet demand—for approximately a third (23) of these materials. In monetary terms, Base Case shortfalls of these problem materials total about $1.3 billion at today's prices.[1] Most of the shortfalls arise in meeting essential civilian sector demands. Defense shortfalls consist of beryllium and three types of carbon fiber, plus a specialty rare earth oxide. Beryllium is discussed in this document. Due to the proprietary nature of their data, the other four defense shortfalls are discussed under separate cover in Appendix 5.

Several major emergency mitigation options to address these potential shortfalls were considered. These options include substitution, increased U.S. buys of foreign supplies from reliable suppliers, and reduced guarantees of material used to produce exported goods. DoD has determined that a substantial share of the originally estimated shortfalls may be cost-effectively mitigated through options other than traditional stockpiling. For the remaining shortfall, DoD recommends that Congress authorize the acquisition of the specific materials in question, as required by section 5(a)(1) of the Strategic and Critical Materials Stock Piling Act (50 USC §98d(a)(1)). The Department is considering legislative proposals requesting authorization for these acquisitions. If the National Defense Stockpile (NDS) already has enough inventory of the given material to cover the remaining shortfall, no additional acquisition is suggested.

[1] Dollar valuations of material amounts are computed using material prices current as of March 31, 2012.

Legislative Requirement

This 2013 NDS Requirements Report on strategic and critical materials is submitted by DoD to Congress pursuant to section 14 of the Strategic and Critical Materials Stock Piling Act (see Appendix 1).[2]

Key Findings and Recommendations

Key Findings: Base Case Shortfalls

For this report, DoD studied 76 materials[3] and evaluated whether they would exhibit shortfalls—insufficient reliable production to meet demands—in the context of the congressionally-mandated 2013 Base Case conflict scenario.[4] Twenty-three were found to exhibit shortfalls. Four of those (three types of carbon fiber plus a specialty rare earth oxide) are discussed under separate cover in Appendix 5 because of the proprietary nature of their data.[5] The rest of this report focuses on the 72 non-proprietary materials that were studied. The 19 shortfalls for the non-proprietary materials are specified in Figures 1, 2, and 3 (in 2012 dollars). Figure 1 presents all 19 materials; Figure 2 provides just the non-rare-earth shortfalls among the 19.[6] Figure 3 separates out only the rare earth shortfalls among the 19.[7] Appendix 6 contains more detailed tables on all of the non-proprietary materials, including shortfalls and existing NDS inventories, both in dollar values and physical quantities.

The shortfall amounts result from a modeling process that computes material demand at all levels of the U.S. economy and then compares material supply with

---

[2] This brief report is intended to summarize findings and recommendations. Underlying methods and assessments are contained in the appendices.

[3] Appendix 2 lists the materials studied, along with their major defense uses.

[4] NDS requirements are based on a congressionally-mandated Base Case scenario, a 4-year scenario that assumes 1 year of conflict (based on the classified, priority Defense Planning Scenarios promulgated by the Secretary of Defense for DoD programming and budgeting purposes) and 3 years of recovery/regeneration. By law, the Base Case must include estimates of all relevant defense sector demands (including attrition and consumption replacement from the conflict year) as well as essential civilian sector demands. For the purpose of this analysis, the 2013 NDS Base Case is postulated to begin in 2015 and last until the end of 2018. For details of these requirements, other assumptions, and definitions, see unclassified Appendix 3 and classified Appendix 4.

[5] The total shortfall for this group is $67.1 million. See Appendix 5 for information on mitigation strategies for these shortfalls.

[6] Figures 1 and 2 include an amount of 52 short tons of beryllium metal, valued at $16.1 million. The supply-demand comparison did not find a shortfall for beryllium metal, but the underlying data assumed that the sole U.S. supplier would be fully in production by the first year of the scenario, 2015. To allow for the possibility that this might not be the case, DoD recommends that 52 short tons of beryllium metal be stockpiled. This amount is approximately equal to two years' worth of defense demand.

[7] Because of rounding, the total shortfall amounts shown in Figures 2 and 3 do not quite add to the total shortfall amount shown in Figure 1.

demand, taking a number of conflict-related factors into account. These factors include unavailability of supply from adversaries, war damage, shipping losses, infrastructure/ability degradation, anti-U.S. orientation, and foreign competition (market share). (See Appendices 3 and 7 for more detail.) The underlying methodology is described briefly in Appendix 7. Based on the purposes for which the materials are used, material demands can be separated into three sectors: defense, emergency investment, and civilian (see Appendix 7 for definitions). Material shortfalls are computed for each of these sectors. That is, a shortfall can represent unsatisfied defense demand, unsatisfied emergency investment demand, unsatisfied civilian demand, or some combination of the three. For the materials shown in Figures 1, 2, and 3, the shortfalls are all in the civilian sector, except for the extrinsically specified goal for beryllium metal, which should be regarded as a defense shortfall.

The Base Case scenario planning factors and other data from which material shortfall estimates are derived (and other factors from which the cost-effectiveness of shortfall mitigation measures is estimated) carry uncertainties because they arise out of projections of future events. The effects of these uncertainties on the ultimate ability of the NDS to meet U.S. demand for these materials in the event of a national emergency are limited through conservative elements built into the DoD NDS requirements planning process. All major planning factors/elements have been approved by a DoD planning group for the Base Case. Such elements include the assumed scope and severity of the conflict scenario and restrictions on relying on certain foreign suppliers to meet defense and critical civilian material needs. DoD believes that the NDS planning process provides reasonable assurance that the stockpile will be able to supply the military, industrial, and essential civilian needs of the United States during a national emergency.

Figure 1. 2013 NDS Base Case Shortfalls for All 19 Non-Proprietary Materials

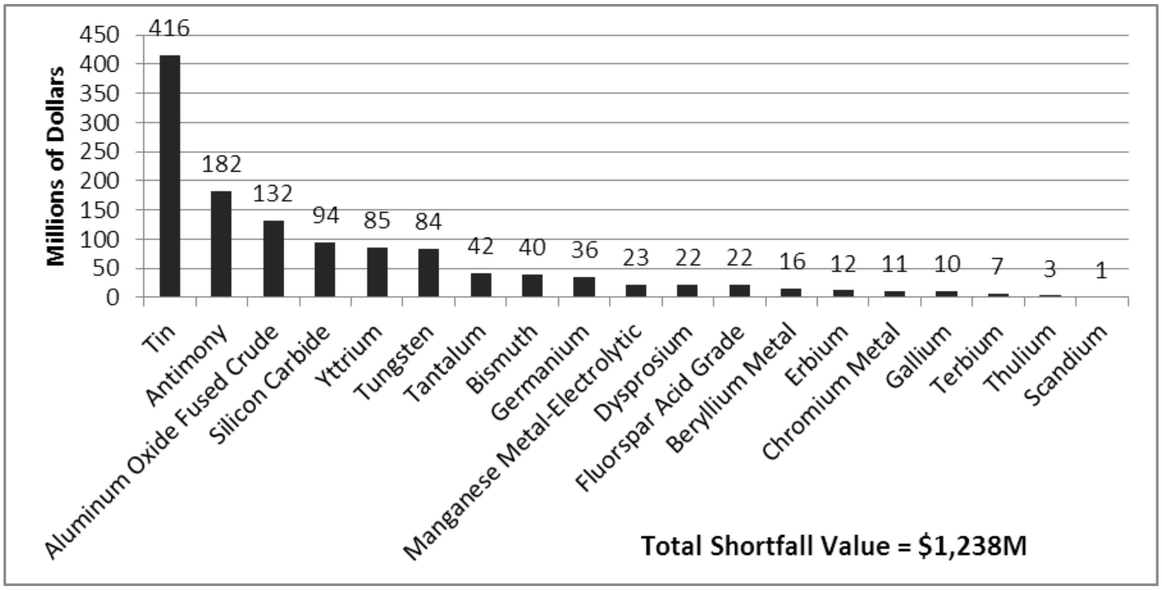


Figure 2. 2013 NDS Base Case Shortfalls for Non-Proprietary Materials (Excluding Six Rare Earths)

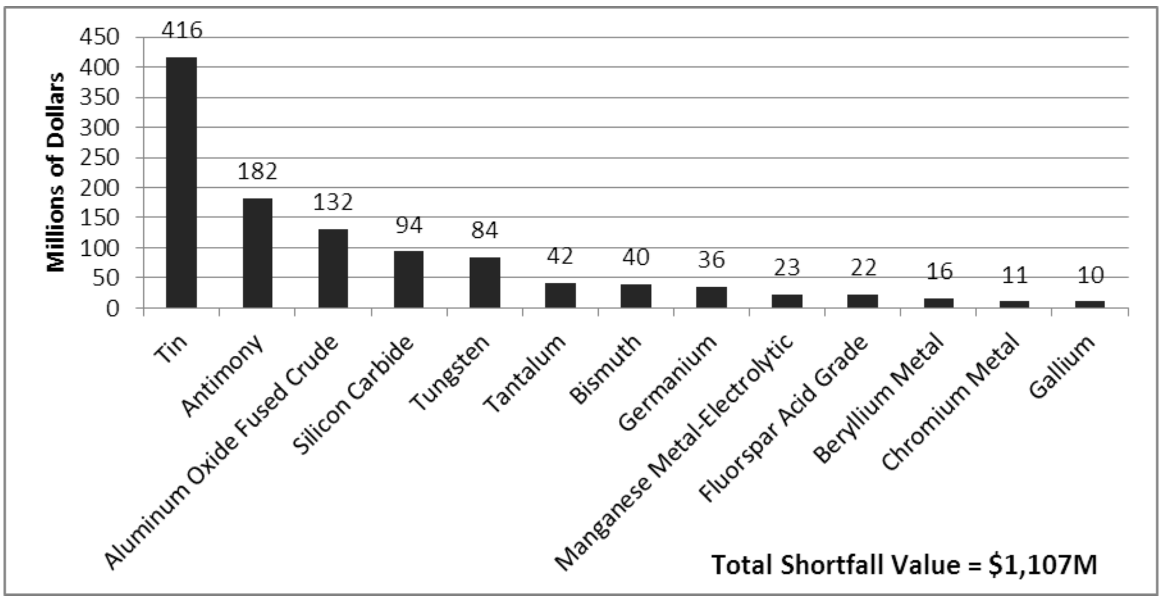
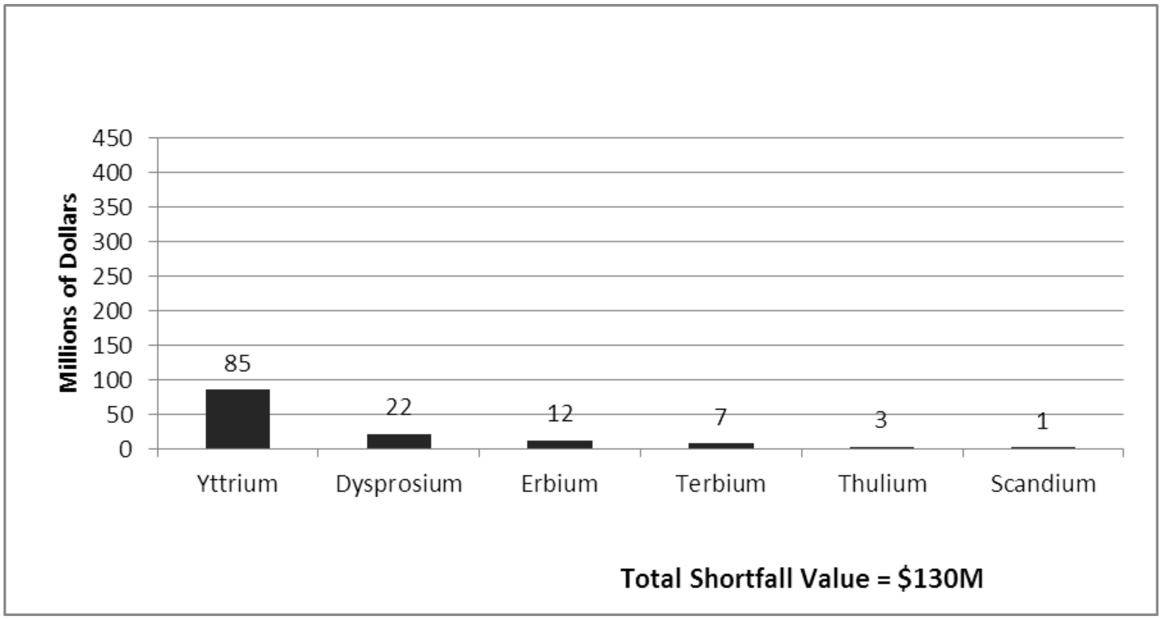


Figure 3. Six Rare Earth Shortfalls in the 2013 NDS Base Case



Recommendations: Mitigation Options and Strategies for the 2013 NDS Base Case Shortfalls

To address these shortfalls, DoD assessed the applicability, costs, and benefits of several types of mitigation initiatives. These initiatives include Federal inventories (including stockpiling), emergency substitution of other materials, emergency U.S. extra buys of shortfall materials from reliable foreign suppliers, and reductions in Government guarantees of shortfall materials contained in or used in the production of exported goods.[8]

An overview of these types of initiatives is as follows.

Inventory approaches: These include the traditional NDS inventorying option of stockpiling, plus other inventory approaches such as buffering. Traditional inventorying is administered by the Defense Logistics Agency (DLA) Strategic Materials on behalf of the Stockpile Manager, the Under Secretary of Defense for Acquisition, Technology and Logistics. The NDS is a stockpile inventory of strategic materials built and held to sustain the defense and essential civilian industrial base of the United States in the event of a national emergency. It is held in reserve; inventories can only be released subject to certain congressional and Presidential authorities. An alternative to creating a traditional stockpile is creating a buffer stock inventory. The buffer stock is to be used in the event

[8] The terms mitigation option, mitigation initiative, and mitigation measure are used synonymously in this report.

of an emergency, but is not subject to formal stockpile release requirements. In this approach, the Government contracts with the material supplier or with the manufacturer(s) that would use the material to purchase, store, and maintain a specified amount of inventory, over and above the amount held in the course of normal business operations. Details are provided in Appendix 8.

Substitution: Base Case shortfall materials may have ready (rapid) substitutes in some or all major application areas. In principle, ready substitutes may provide the same, better, or lesser performance, at greater or lower cost. For this study, DoD has identified a number of promising ready, near-same performance level, low-to-no-cost (to the Government) substitution possibilities that should be available from reliable sources in amounts that do not create other important shortfalls during a Base Case emergency. Details about these substitutes are provided in Appendix 9.

Extra U.S. Buys: The 2013 NDS Base Case assumption is that the United States will be able to obtain (buy) at least a "normal market share" of reliable countries' production of a given material during the Base Case emergency. The "Extra Buy" option, as discussed here, postulates that the United States will also be able to buy—on a bilateral basis negotiated during the emergency—a larger-than-normal market share of any extra production that specific foreign reliable countries would be able to produce from their existing capacity during the emergency. Details are provided in Appendix 10.

Export Reductions: The materials needed to produce the goods and services exported by the United States constitute a source of material demand. If exports of goods and services were reduced, demand for materials would tend to be lower, and, hence, material shortfalls would tend to be smaller. Although the terms "reduced exports," "reduced U.S. exports," and "export reductions" are used throughout this report to refer to this mitigation option, the U.S. Government would not be reducing exports, even in this national emergency scenario. In this context, reducing exports only means that the U.S. Government would not guarantee the availability of materials to produce *all* of the goods that are exported in the Base Case, but only a fraction of them.[9] For more information, see Appendix 16.

DoD recommends the material-by-material mitigation strategies for all of the 19 (non-proprietary level) shortfalls that are depicted in Figure 4. The figure shows the respective shares (fractions) of the Base Case shortfalls that DoD proposes mitigating

[9] This approach assigns a low priority to ensuring that in a national emergency, materials would be available to support a larger-than-Base-Case portion of exports, but would not directly reduce private demands for those materials. In practice, the Government might find it necessary to allocate selected materials among end uses to ensure that essential requirements were met and that limited supplies were not diverted to lower priority uses.

with extra emergency buys, substitutions, export reductions, and some form of stockpiling/Federal inventorying.

The order in which these emergency mitigation options are applied to build the shortfall mitigation strategies shown in Figures 4 through 6 is the same for all materials: (1) seek to buy/import somewhat larger-than-normal U.S. market shares of any extra production of the shortfall material that reliable foreign suppliers are able to produce by ramping up to full (three-shift) production levels within their existing capacity; (2) permit ready substitute materials to mitigate some or all of any remaining shortfalls, up to the potential for such substitution; (3) during the conflict year (the first year), if needed, place greater than Base Case restrictions on U.S. guarantees of material to produce exports of shortfall-material-intensive products (but do not restrict any defense-related exports to friends and allies during this period). If any projected shortfall remains after "applying" these options, plan to acquire and stockpile the remaining estimated amounts of the shortfall material before the emergency. If the stockpile already has enough inventory to cover that remaining amount, plan to keep that amount of inventory. If the NDS does not have enough inventory, plan to acquire it. If the NDS has more than enough inventory to cover that remaining amount, then plan to sell off the surplus inventory and use it, as appropriate, to buy any remaining shortfalls of other materials.[10]

The rationale for applying the mitigation options in this order is as follows: extra buys would be of the needed shortfall material. If there are advance agreements with friends and allies, the material should be available within existing capacity comparatively easily, albeit at premium prices. On the other hand, those costs would only have to be incurred if the postulated national emergency occurred, which may be unlikely. Substitution possibilities have been assessed for their feasibility but involve using other materials, not obtaining more of the shortfall materials themselves. Consequently, they are deemed (here) somewhat less attractive as a mitigation option than extra buys of the same material. The "reduced U.S. exports" option may be considered problematic. It has been judged to be less likely to be successful than using extra buys and ready substitution possibilities (see Appendix 11). On the other hand, this option imposes no monetary cost on the Government, the U.S. Government guarantees of materials for defense-related exports to friends and allies are not reduced, and the reduction would only be for the first year of the scenario. Nevertheless, it seems prudent at this point to resort to this option only after mitigating the shortfall as much as feasible via extra buys and substitution. Last, Federal inventories (particularly stockpiling) are generally considered reliable, but they are also generally more expensive, on an expected cost basis, than the other mitigation measures evaluated.

---

[10] Traditional inventorying/stockpiling rather than buffering is recommended here because it is more cost-effective for those materials where some form of inventorying is appropriate.

Figure 4. DoD's Proposed Mitigation Strategies for 2013 Base Case Shortfall Materials

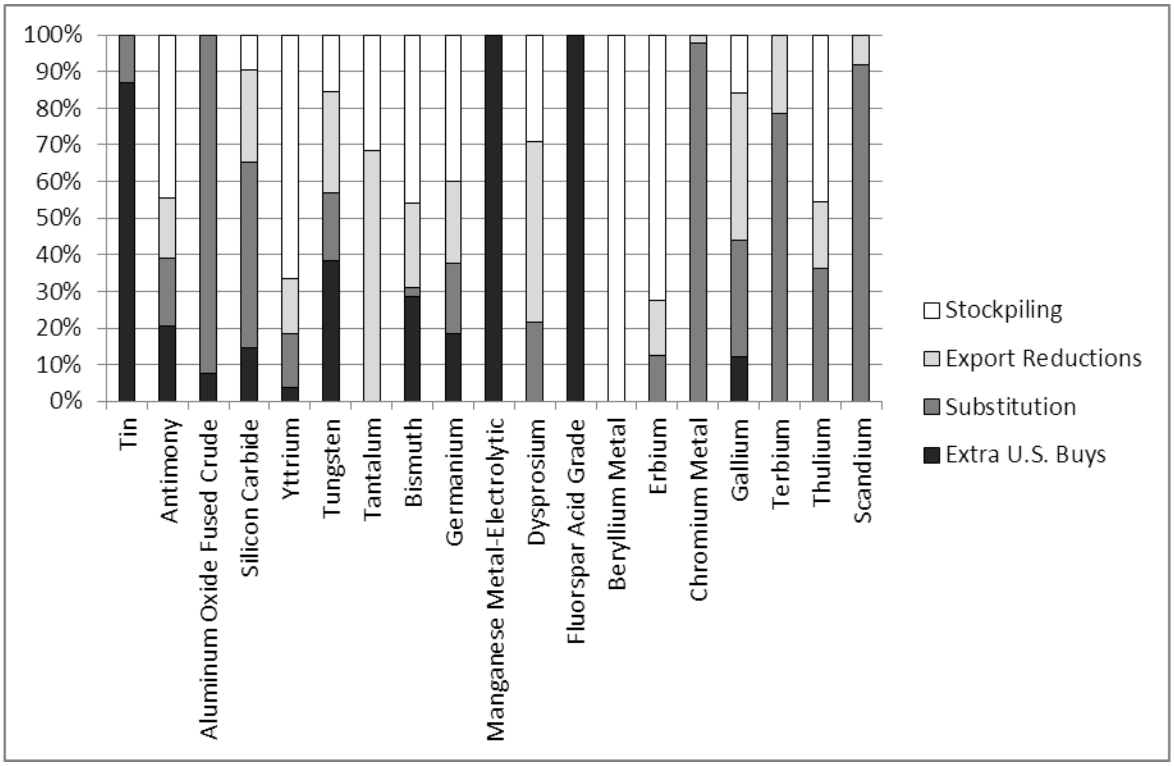


Figure 4 shows that extra U.S. buys of shortfall materials from reliable foreign sources during the emergency should be able to mitigate sizable fractions of the Base Case shortfalls.[11] The overall shortfall diminishes from $1.2 billion in the Base Case to $711 million in the case where extra buys are assumed. For several materials (tin, manganese metal, and acid-grade fluorspar), much or all of the shortfall appears to be addressed by the extra buy option. On the other hand, for other shortfall materials—such as tantalum, chromium metal, and several others—extra buys offer few or no mitigation opportunities.

Immediate, low-to-no-cost substitution possibilities should, according to the evidence, provide quite significant mitigation opportunities for at least some of these Base Case shortfalls. Large substitution opportunities (relative to the shortfall amounts[12]) appear to exist for aluminum oxide, silicon carbide, chromium metal, and terbium, for

[11] For this study, a variety of experts assessed the likelihood that emergency extra buys, substitution, export reductions, and inventorying would succeed in mitigating specific quantities of each Base Case shortfall. These likelihoods were used to estimate the share that each mitigation option/component would contribute to a given material's shortfall mitigation strategy. See Appendix 11 for details.

[12] If a shortfall represents a small fraction of annual demand (e.g., chromium metal), it may still be eliminated by modest substitution possibilities.

example. Moderate substitution opportunities exist for several others. For other shortfall materials, however, such as bismuth and tantalum, ready substitution looks quite limited as a mitigation option. When substitution is used along with extra U.S. buys, the shortfall drops from $711 million to $404 million, an incremental reduction of $307 million.

The reduced exports mitigation option results in lessened shortfalls for all of the materials (except the extrinsically specified goal of beryllium metal). But since export reduction is a lower priority mitigation measure, it does not show up in Figure 4 as a large fraction when higher priority mitigation measures are effective. Export reduction appears to be a preferable mitigation measure for tantalum, dysprosium, and gallium. When reduced exports are used in conjunction with extra U.S. buys and substitution, the shortfall has a further incremental reduction of $111 million, dropping from $404 million to $293 million. This remaining shortfall amount must be addressed by stockpiling.

Figures 5 and 6 separate these 19 shortfall materials and their mitigation strategies into the non-rare earths and the rare earths, respectively. Appendix 5 presents shortfall mitigation approaches for the proprietary-level materials along with a general discussion of these materials.

Figure 5. DoD's Proposed Mitigation Strategies for Non-Rare Earth Shortfalls

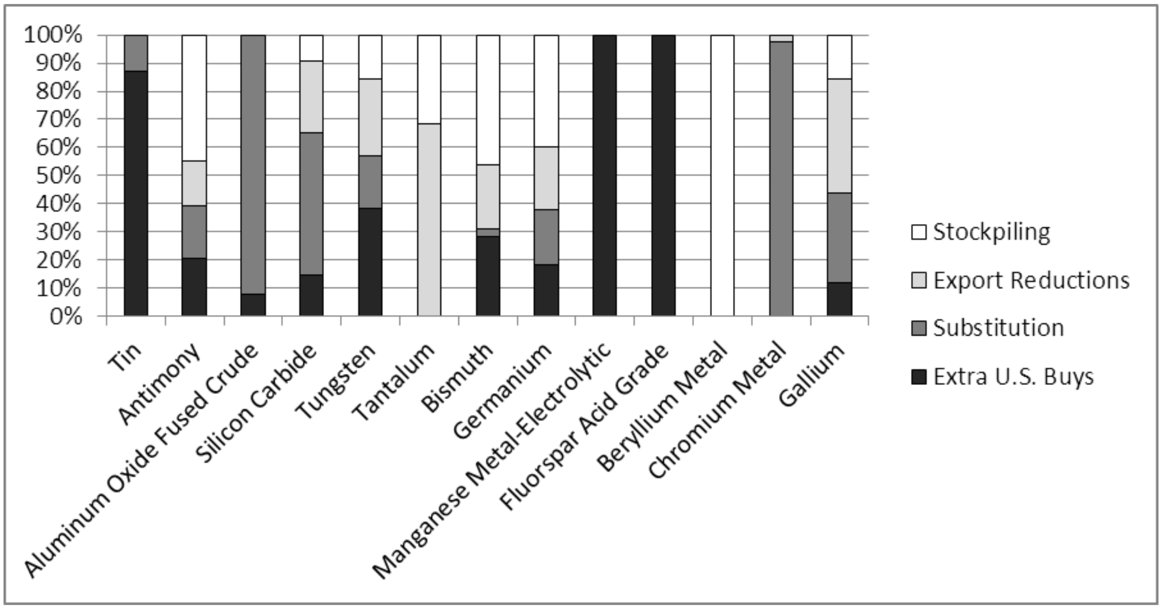


Figure 6. DoD's Proposed Mitigation Strategies for Rare Earth Shortfalls

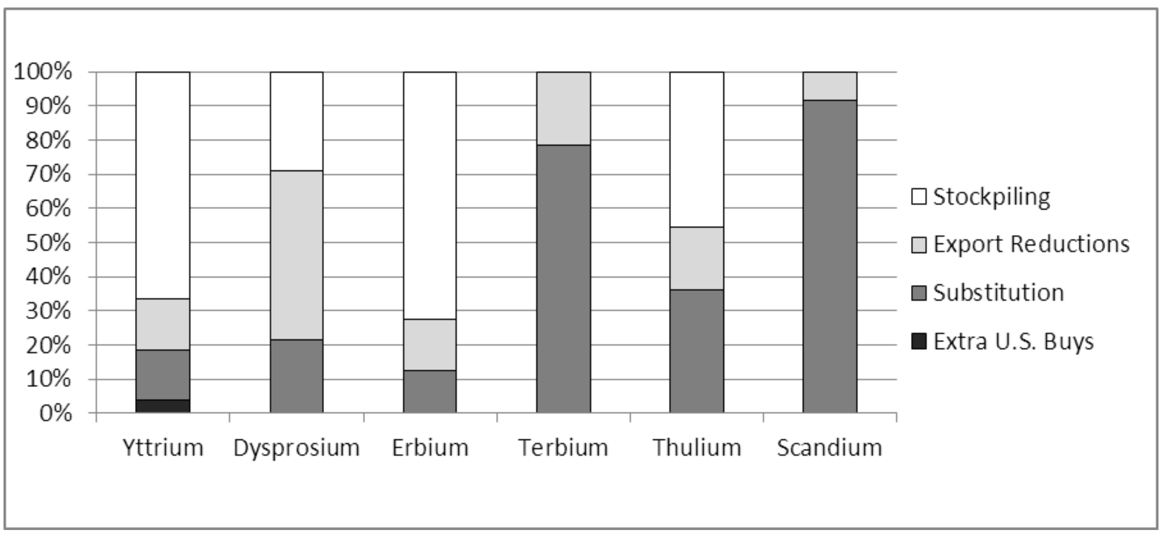


Figure 7 depicts the approximate cost of the stockpiling portion of the mitigation strategy for the 19 non-proprietary level shortfall materials in the 2013 Base Case. (Where the shortfall can be ameliorated by measures other than stockpiling, the amount shown in Figure 7 is zero.) Some of the stockpiling portion can be satisfied by the existing NDS inventory.[13] In Figure 7, the amount covered by existing inventory is shown in black. The white portion of each bar represents the amount of the material that will need to be acquired. It should be noted, however, that when the Government's sale

---

[13] See Appendix 3 for information on NDS inventories as of June 30, 2012.

of stockpiled materials (after they are no longer needed to mitigate supply disruption risks) is considered, the net expected cost of stockpiling drops considerably (see Appendix 12). Figure 7 shows stockpiling costs (at current prices) for all of the 19 non-proprietary shortfall materials; Figure 8 shows them for the non-proprietary shortfall materials except for rare earths; and Figure 9 shows them for the non-proprietary rare earth shortfall materials. For information on stockpiling strategies and costs for the proprietary materials, see Appendix 5.

Figure 7. Cost of the Stockpiling Portion of the Mitigation Strategy

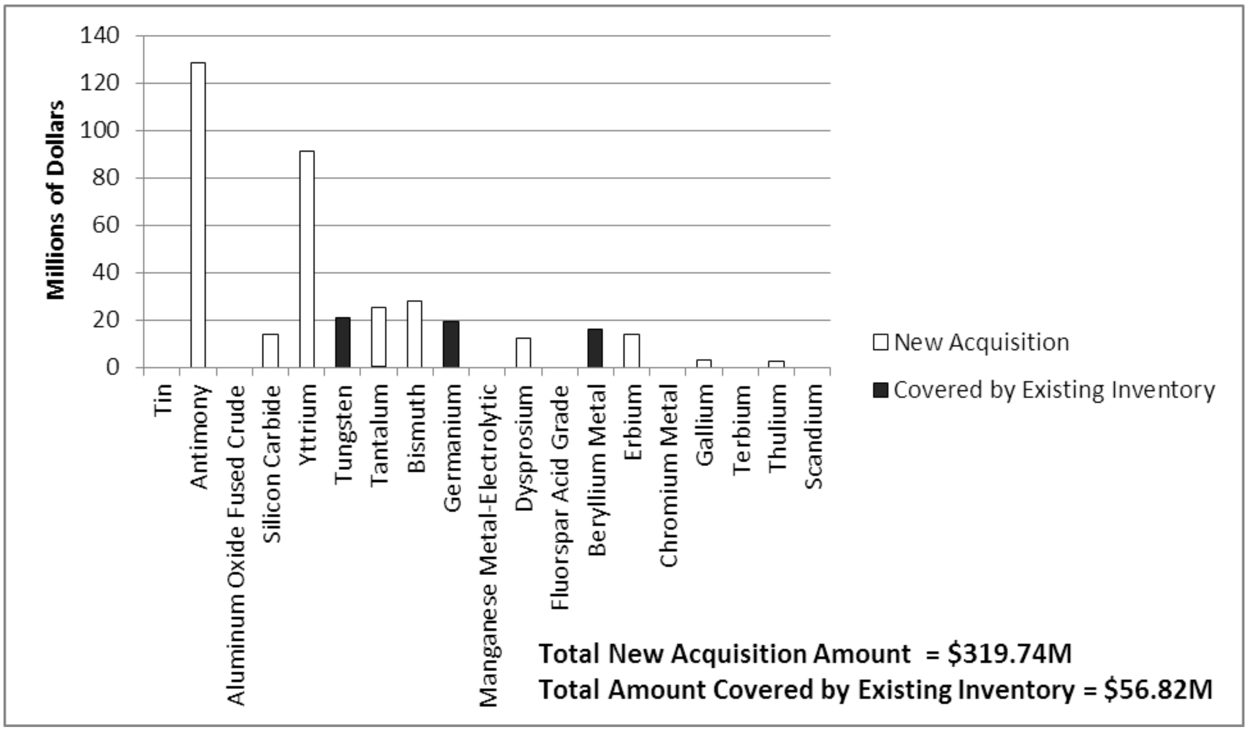


Figure 8. Cost of the Stockpiling Portion of the Mitigation Strategy (Non-Rare Earths)

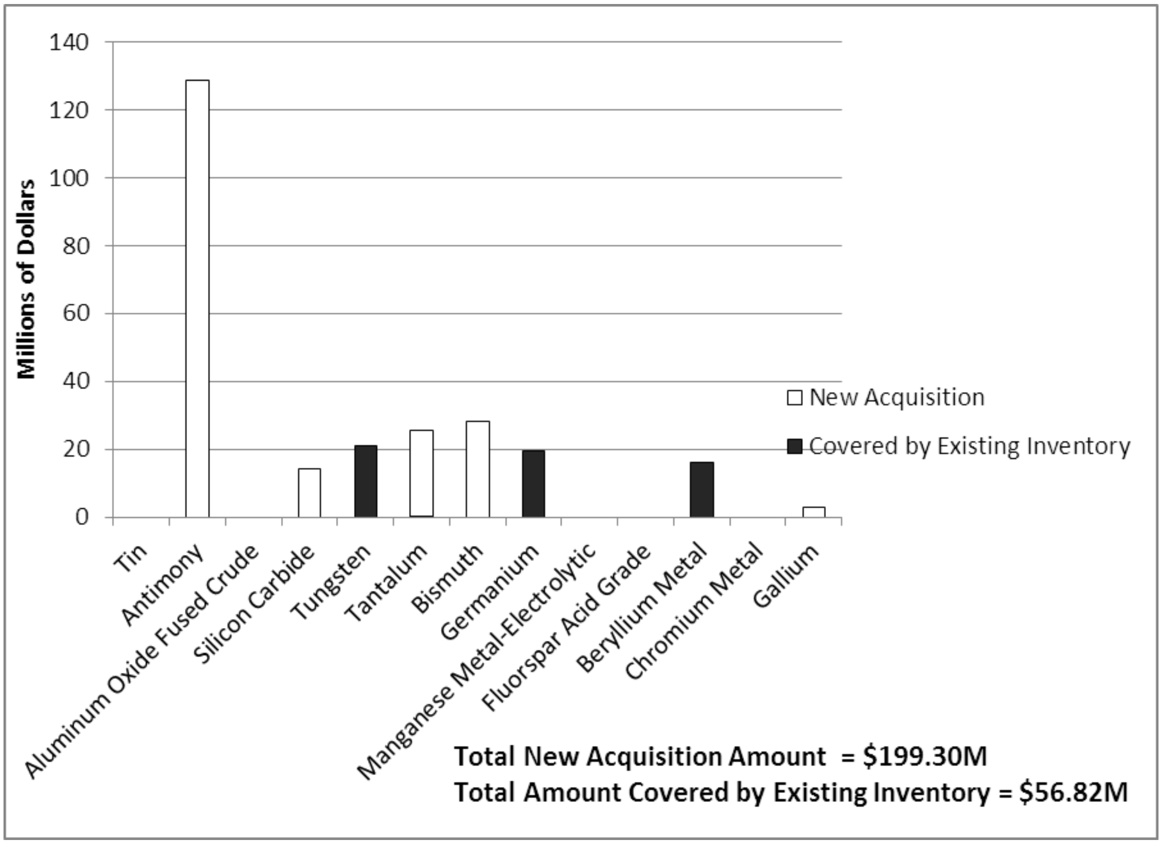
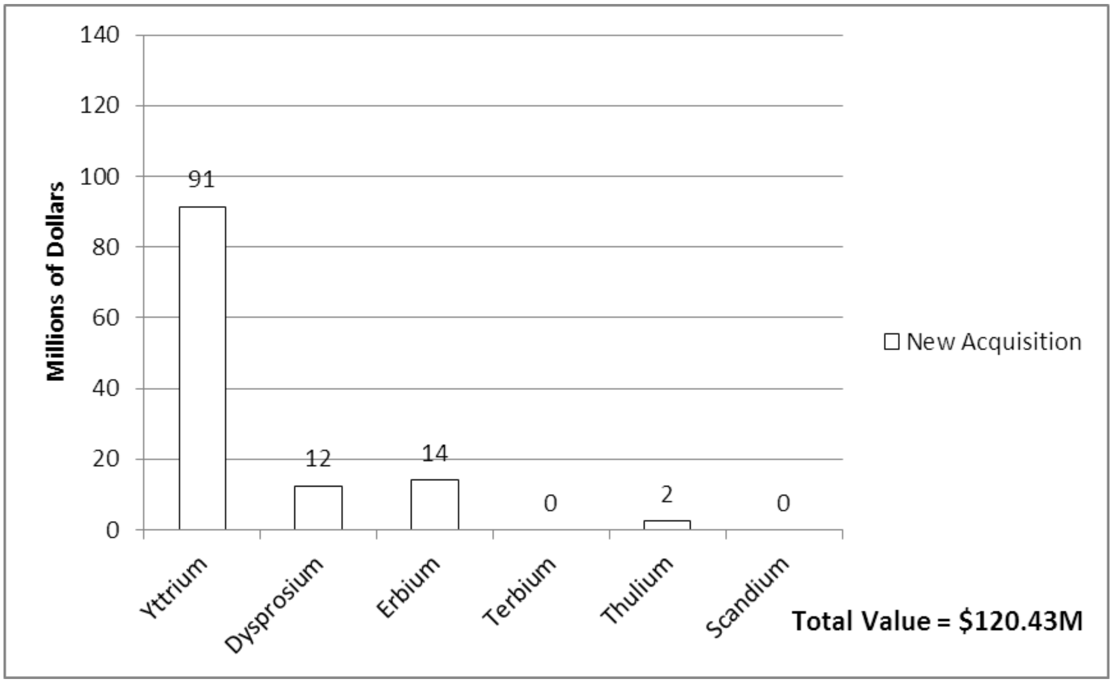


Figure 9. Cost of the Stockpiling Portion of the Mitigation Strategy (Rare Earths)



Recommendations: Setting Priorities among Base Case Shortfalls

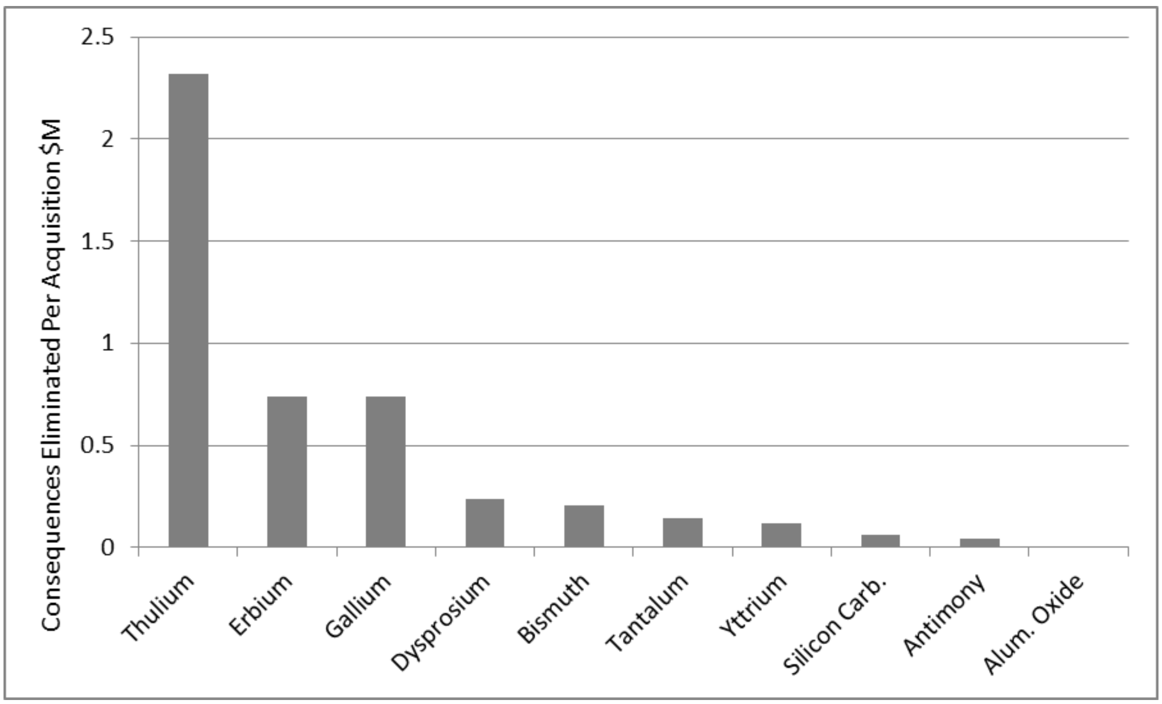
To assess priorities among shortfall materials to be acquired for stockpiling, DoD conducted several types of elicitations and risk analyses, drawing upon the new analytic structure and techniques that were developed for this purpose, known as the Risk Assessment and Mitigation Framework for Strategic Materials (RAMF-SM). The features of RAMF-SM are described in Appendix 12.

If priorities are to be set among the non-proprietary level shortfall materials for expending up-front resources to mitigate them (via stockpiling), DoD recommends the priority ranking shown in Figure 10. This ranking is based on the ratio of each material's shortfall consequence score (for the 2013 NDS Base Case) to its shortfall stockpiling acquisition cost, in decreasing order. The ratio is an expression of the shortfall risk mitigated per dollar spent on material stockpiling.

A large group of experts from Government, industry, and academia assessed the consequences of the shortfall for each material. The group was asked to assess, using calibrated ratio scales, the consequences (military, economic, and political, collectively) that would result to the nation if each material shortfall were to remain unmitigated during the Base Case scenario, considering both the applications in which each material is used and the quantity of each material in shortfall. As discussed in Appendix 12, a consequence score of 10 corresponds to a material shortfall with severe consequences due to its magnitude relative to the annual demand, the importance of the material's applications, or the impact of the shortfall on the U.S. industrial base. Because these estimates are the product of subjective expert judgment, it should be noted that they carry some level of uncertainty. Because all of these shortfalls arise out of the same scenario (the Base Case) and they are all shortfalls for civilian applications, relative consequences are a reasonable basis for assessing the approximate relative importance of, and hence prioritizing, the shortfalls. Details of how the scores are constructed are included in Appendix 12. The shortfall stockpiling acquisition cost for each material for this calculation was the cost of the shortfall amount divided by the probability of success of stockpiling (see Appendix 11).

It is noted that these results may be driven by stockpiling acquisition costs as well as the potential consequences of the shortfalls. The shortfall of thulium, for example, is small and thus its stockpiling acquisition cost is low, relative to its consequence score, when compared to those of the other materials. Therefore, the ratio of consequence to acquisition is comparatively large.

Figure 10. Priority Ranking Among (Non-Proprietary) Shortfall Materials Recommended for Stockpile Acquisition (Base Case)



Additional Cases and Analyses

Although the 2013 NDS Base Case assessments are the principal analyses DoD conducts for the 2013 NDS Requirements Report, the Strategic Materials Stock Piling

Act also requires analysis of several other cases, including a more demanding case than the Base Case. As a result, four principal other cases, beginning with the alternative base case, which is more demanding than the Base Case, were examined.

Alternative Base Case

In the Base Case, foreign material supply that is available to the United States is generally considered to be usable to satisfy defense demands for material. The main exception is material that comes from countries that dominate the market for that material. See Appendix 3 for more details. An alternative assumption is to consider only supply from the United States and Canada as capable of offsetting defense demand. This constraint is so important that the case where it is imposed is known as the alternative base case.

For the 72 non-proprietary materials, 26 of them have shortfalls in the alternative base case, as opposed to 19 in the Base Case. The total value of their shortfalls is \$2.7 billion as opposed to \$1.2 billion in the Base Case. Twelve of the materials have defense shortfalls, and these persist throughout the whole scenario. Figure 11 shows the 2012 dollar values of the shortfalls in the Base Case and the alternative base case. In the figure, the dark portion of the bar represents the Base Case shortfall and the lighter portion of the bar represents the incremental shortfall from the alternative base case. Thus the total length of the bar represents the shortfall in the alternative base case.[14]

Examination of Figure 11 shows that the most striking case is natural rubber. The United States and Canada produce no natural rubber, so under the assumptions of the alternative base case, all the defense demand for natural rubber (\$1.2 billion) becomes a shortfall. (This value is shown off the scale of the chart, so that differences among the other values can be discerned more easily.) This constitutes the major portion of the incremental shortfall in the alternative base case. In contrast, for several materials, the United States and Canada together generate enough supply to cover defense needs, so there is no change in shortfalls from the Base Case.

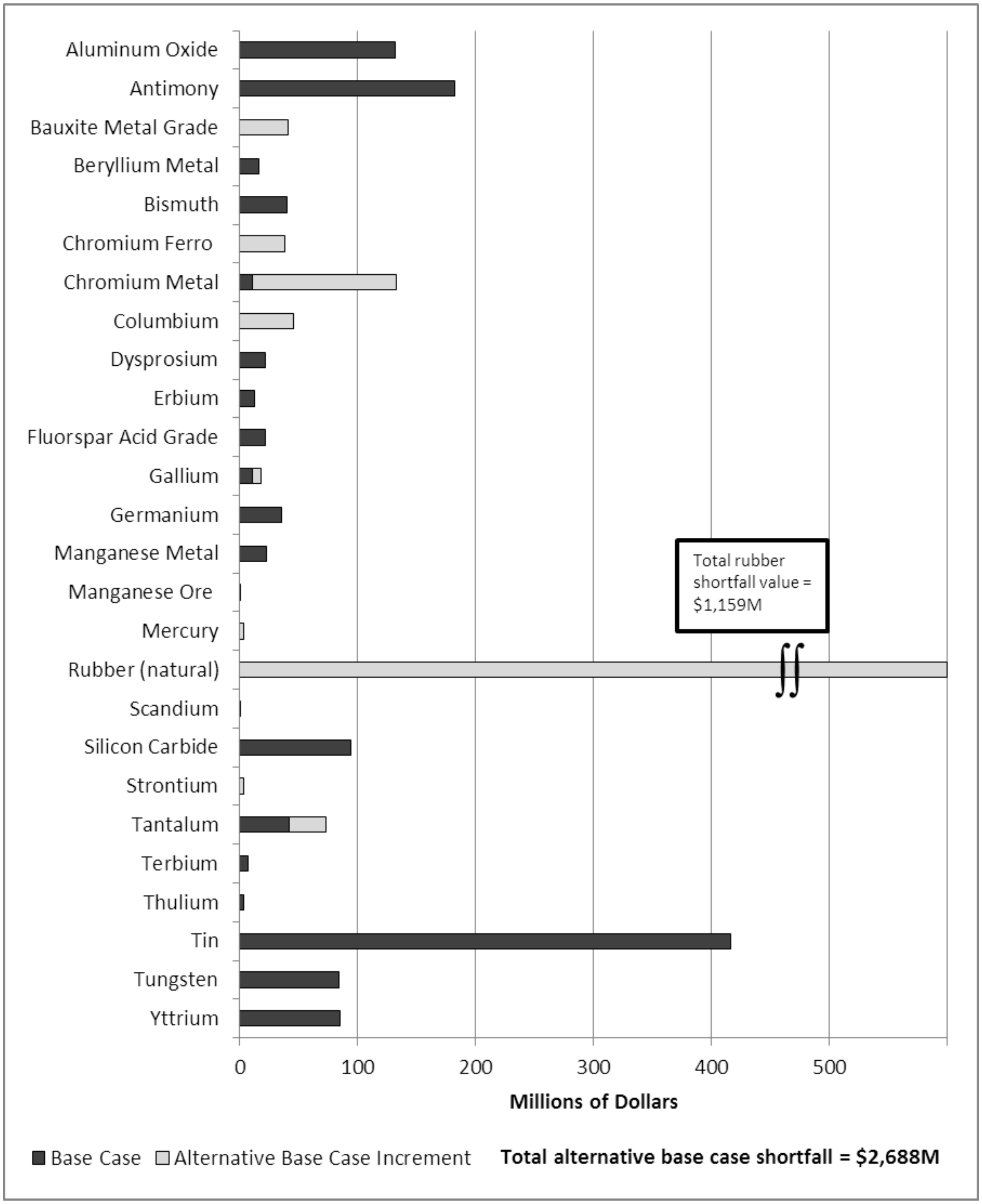
The alternative base case might warrant mitigation assessments similar to the Base Case. If there is sufficient congressional interest, DoD can pursue such assessments. One such assessment might include the role of synthetic rubber as a possible substitute for natural rubber.

Appendix 13 presents additional information about the alternative base case, including defense and civilian shortfall quantities for all the non-proprietary materials.

---

[14] Figure 11 includes the extrinsically specified goal of 52 short tons of beryllium metal. As in the Base Case, the supply-demand comparison for the alternative base case did not find any shortfall for beryllium metal. See footnote 6.

Figure 11. Shortfalls in the Alternative Base Case



Peacetime Supply Disruption Cases

A set of cases was examined where conditions were essentially as in peacetime, but the supply from one particular country was cut off for a year, due to postulated export cutoffs or political unrest. Three different cases were examined, one each for China, Russia, and South Africa. In each case, shortfalls occurred when the indicated country was a major producer of the material.

Appendix 13 discusses the assumptions behind the peacetime supply disruption cases in more detail and presents the shortfall results for each material. Appendix 13 also discusses a number of additional sensitivity cases.

Next Steps

Additional materials not included in this report need to be assessed. DoD was not able to develop enough data to assess a number of other materials nominated by the Military Services and defense agencies in time for this report. Acquiring the requisite data will be a priority. Cadmium Zinc Tellurium substrates and additional high performance fibers are examples of the types of materials that will be modeled in future reports.

DoD also recognizes that the top-level shortfall and mitigation assessments contained in this report need to be supplemented by continuing and in-depth downstream assessments of key defense and critical supply chains for strategic and critical materials. The justification for such analyses comes from the observation that the absence of a top-level shortfall does not, per se, lead to the conclusion that there are not vulnerabilities and choke points further downstream. DoD intends to vigorously pursue stronger downstream supply chain assessment capabilities, including the ability to identify potential domestic and foreign single points of failure.

Linking these 2013 assessments with the contingency preparedness planning process described in the DoD report for section 853 of the National Defense Authorization Act for Fiscal Year 2012 (Public Law 112-81)[15] is another priority.

---

[15] *Report to Congress on Assessment of Feasibility and Advisability of Establishment of Rare Earth Material Inventory*, Draft Report, Office of the Secretary of Defense, September 2012.

Structure of this Report

This summary report constitutes the main body of the 2013 NDS Requirements Report to Congress. The report also includes 17 appendices that present the detailed analysis of the following topics:

- Appendix 1 presents the text of relevant portions of the Stock Piling Act.
- Appendix 2 lists the materials studied for this report, along with some of their key defense uses.
- Appendix 3 describes the assumptions underlying the Base Case scenario, at an unclassified level.
- Appendix 4, available under separate cover, provides a classified description of the Base Case.
- Appendix 5, available under separate cover, contains an assessment of proprietary materials.
- Appendix 6 presents the shortfalls for the non-proprietary materials. It also lists the NDS inventories (as of June 30, 2012) for these materials, and some additional informative tables.
- Appendix 7 briefly describes the methodology used to compute material demands, supplies, and shortfalls.
- Appendix 8 describes Federal inventorying methods (stockpiling and buffer stocks).
- Appendix 9 discusses in detail the substitution mitigation option and its results.
- Appendix 10 discusses in detail the extra buy mitigation option and its results.
- Appendix 11 describes how the success probabilities of the various mitigation options were derived, and shows how they are combined with the material shortfall information to develop mitigation strategies.
- Appendix 12 discusses in detail the process for assessing the risks associated with shortfalls of materials and the costs of the various mitigation measures.
- Appendix 13 presents detailed results for the alternative base case and the peacetime supply disruption cases, and briefly describes some additional cases that were examined.
- Appendix 14 focuses on the process used to identify which civilian demands (for goods and services, and thus for the materials necessary to produce them) are considered essential. The resulting demand reduction factors (to omit nonessential demand) are presented.

- Appendix 15 contains the questionnaire that was presented to subject matter experts to assess the reliabilities of countries that supply goods, services, and materials.
- Appendix 16 discusses in detail the "export reduction" mitigation option and its results.
- Appendix 17 defines the abbreviations and acronyms used in this report.

Appendix 1
Strategic and Critical Materials
Stock Piling Act

(a) Not later than January 15 of every other year, the Secretary of Defense shall submit to Congress a report on stockpile requirements. Each such report shall include—

(1) the Secretary's recommendations with respect to stockpile requirements; and

(2) the matters required under subsection (b).

(b) Each report under this section shall set forth the national emergency planning assumptions used by the Secretary in making the Secretary's recommendations under subsection (a)(1) with respect to stockpile requirements. The Secretary shall base the national emergency planning assumptions on a military conflict scenario consistent with the scenario used by the Secretary in budgeting and defense planning purposes. The assumptions to be set forth include assumptions relating to each of the following:

(1) The length and intensity of the assumed military conflict.

(2) The military force structure to be mobilized.

(3) The losses anticipated from enemy action.

(4) The military, industrial, and essential civilian requirements to support the national emergency.

(5) The availability of supplies of strategic and critical materials from foreign sources during the mobilization period, the military conflict, and the subsequent period of replenishment, taking into consideration possible shipping losses.

(6) The domestic production of strategic and critical materials during the mobilization period, the military conflict, and the subsequent period of replenishment, taking into consideration possible shipping losses.

(7) Civilian austerity measures required during the mobilization period and military conflict.

(c) 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.

(d) The Secretary shall also include in each report under this section an examination of the effect that alternative mobilization periods under the military conflict scenario required under subsection (b), as well as a range of other military conflict scenarios addressing potentially more serious threats to national security, would have on the Secretary's recommendations under subsection (a) (1) with respect to stockpile requirements.

(e) The President shall submit with each report under this section a statement of the plans of the President for meeting the recommendations of the Secretary set forth in the report.

Appendix 2
Materials Studied

For the 2013 National Defense Stockpile (NDS) Requirements Report, 76 materials were studied.[1] Because of the proprietary nature of the data, the analysis and results for four of these materials are presented under separate cover (Appendix 5). These four materials comprise three types of carbon fibers and a specialty rare earth oxide.

The remaining 72 materials can be organized into six different groups, as follows:

- Metals (28 materials, excluding precious metals and rare earths)
- Precious Metals (7)
- Ores and Compounds (11)
- Miscellaneous Non-Metals (7)
- Alloys (3)
- Rare Earths (16)

Of these 72 materials, 58 were also analyzed in the 2011 NDS requirements study. The 58 included seven rare earth materials: dysprosium, europium, neodymium, praseodymium, samarium, terbium, and yttrium. Materials analyzed in the 2013 study but not the 2011 study include magnesium, quartz crystal (synthetic), selenium, silicon, strontium, and nine rare earth elements: scandium, lanthanum, cerium, gadolinium, holmium, erbium, thulium, ytterbium, and lutetium. (Thus, the 2013 study analyzes all the rare earth elements except promethium.)

Materials analyzed in the 2011 study but not the 2013 study comprise nine types of high-performance fiber and three types of specialty steel.

Table 2-1 lists the 72 materials, organized by the above grouping. Table 2-2 provides an alphabetical list of the materials. Table 2-3 lists the materials and their important defense uses.

[1] The materials examined in the 2013 study were nominated by the Services, defense agencies, and/or the Office of the Secretary of Defense as worthy of analysis because of their important defense uses and possible fragility of supply.

Table 2-1. Materials Examined in the 2013 NDS Study

Metals (28)
Aluminum Metal
Antimony
Beryllium Metal
Bismuth
Cadmium
Chromium Metal
Cobalt
Columbium
Copper
Gallium
Germanium
Hafnium
Indium
Lead
Lithium
Magnesium
Manganese Metal, Electrolytic
Mercury
Molybdenum
Nickel
Strontium
Tantalum
Tin
Titanium Sponge
Tungsten
Vanadium
Zinc
Zirconium Metal
Rare Earths (16)
Cerium
Dysprosium
Erbium
Europium
Gadolinium
Holmium
Lanthanum
Lutetium
Neodymium

Table 2-1. Materials Examined in the 2013 NDS Study (concluded)

Rare Earths, continued
Praseodymium
Samarium
Scandium
Terbium
Thulium
Ytterbium
Yttrium
Precious Metals (7)
Iridium (Platinum Group)
Palladium (Platinum Group)
Platinum (Platinum Group)
Rhenium
Rhodium (Platinum Group)
Ruthenium (Platinum Group)
Silver
Ores and Compounds (11)
Aluminum Oxide Fused Crude
Bauxite Metal Grade Jamaica & Suriname
Bauxite Refractory
Beryl Ore
Chromite, Chemical, Refractory, and Metallurgical Grade Ore
Fluorspar, Acid Grade
Fluorspar, Metallurgical Grade
Manganese Dioxide Battery Grade Natural
Manganese Dioxide Battery Grade Synthetic
Manganese Ore, Chemical & Metallurgical Grades
Zirconium Ores and Concentrates
Miscellaneous Non-Metals (7)
Boron
Quartz Crystal (synthetic)
Rubber (natural)
Selenium
Silicon
Silicon Carbide
Tellurium
Alloys (3)
Beryllium Copper Master Alloy
Chromium, Ferro
Manganese, Ferro

Table 2-2. Alphabetical List of Materials Examined in the 2013 NDS Requirements Study

Aluminum Metal	Manganese Dioxide Battery Grade Synthetic
Aluminum Oxide Fused Crude	Manganese Ferro (C and Si)
Antimony	Manganese Metal—Electrolytic
Bauxite Metal Grade Jamaica & Suriname	Manganese Ore Chem/Metal Grade
Bauxite Refractory Grade	Mercury
Beryl Ore	Molybdenum
Beryllium Copper Master Alloy	Neodymium
Beryllium Metal	Nickel
Bismuth	Palladium (Platinum Group)
Boron	Platinum (Platinum Group)
Cadmium	Praseodymium
Cerium	Quartz Crystal (synthetic)
Chromite Ore (chemical, refractory, and metallurgical grades)	Rhenium
Chromium Ferro (Ferrochromium)	Rhodium
Chromium Metal	Rubber (natural)
Cobalt	Ruthenium
Columbium	Samarium
Copper	Scandium
Dysprosium	Selenium
Erbium	Silicon
Europium	Silicon Carbide
Fluorspar acid grade	Silver
Fluorspar metallurgical grade	Strontium
Gadolinium	Tantalum
Gallium	Tellurium
Germanium	Terbium
Hafnium	Thulium
Holmium	Tin
Indium	Titanium (sponge)
Iridium (Platinum Group)	Tungsten
Lanthanum	Vanadium
Lead	Ytterbium
Lithium	Yttrium
Lutetium	Zinc
Magnesium	Zirconium Metal
Manganese Dioxide Battery Grade Natural	Zirconium Ores and Concentrates

Table 2-3. Important Defense Uses of Strategic Materials

Material	Important Defense Uses
Aluminum Metal	Missiles and space vehicles, aircraft, littoral combat ships, Architectural and structural metal production
Aluminum Oxide Fused Crude	Abrasive products, Clay building materials and refractories manufacturing, Soaps and cleaners
Antimony	Ammunition, Plastics material and resins, Storage batteries
Bauxite Metal Grade, Jamaica and Suriname	Aluminum production
Bauxite Refractory	Primary ferrous metal products, Ferrous metal foundries, Primary aluminum production
Beryl Ore	Gold, silver and other metal ore mining
Beryllium Copper Master Alloy	Electronic components, Relays and industrial controls, Wiring devices
Beryllium Metal	Computer, IT and nuclear applications
Bismuth	Primary aluminum production, Ammunition, Optical instruments and lenses
Cadmium	Storage batteries, Broadcast and wireless communications equipment, Aircraft
Cerium	Semiconductors and electron tubes, Storage batteries, Glass products except containers, Motor vehicle parts
Chromite, Chemical, Refractory and Metallurgical Grade Ore	Basic inorganic chemicals, Basic organic chemicals, Pharmaceuticals and medicines
Chromium, Ferro	Motor vehicle parts, Aircraft, Metal valves, Production of stainless steel
Chromium Metal	Aircraft, Missiles and space vehicles, Aircraft engines and engine parts
Cobalt	Aircraft engines and engine parts, Search, detection and navigation instruments, Semiconductors and electron tubes
Columbium	Aircraft, Missiles and space vehicles, Aircraft engines and engine parts
Copper	Metal valves, Fiber optic and other cable, Broadcast and wireless communications equipment, Munitions, Brass shell casings, Shaped charge liners
Dysprosium	Nuclear control rods, Magnets, Ceramics for electronics
Erbium	Communications, energy wires and cables, Nonferrous metal products, Semiconductors and electron tubes

Table 2-3. Important Defense Uses of Strategic Materials (continued)

Material	Important Defense Uses
Europium	Nuclear control rods, Lasers, Phosphors for lighting and displays
Fluorspar, Acid Grade	Basic inorganic chemicals, plastics materials and resins, Primary aluminum production
Fluorspar, Metallurgical Grade	Primary ferrous metal products, glass and glass products, except containers, Ferrous metal foundries
Gadolinium	Computer storage devices, semiconductors and electron tubes, electro-medical apparatus, magnetic and optical recording devices
Gallium	Semiconductors and electron tubes, scientific research and development
Germanium	Fiber optics, Infrared optics, electronics
Hafnium	Electric lamp bulb and part manufacturing, semiconductors and electron tubes, Metal cutting and forming machine tool, Miscellaneous fabricated metal products
Holmium	Electronic components, Semiconductors and electron tubes, Other fabricated metal products
Indium	Nonferrous metal products, except copper and aluminum, Scientific research and development, Semiconductors and electron tubes
Iridium (Platinum Group)	Electronic components, Basic inorganic chemicals, Aircraft engines and engine parts
Lanthanum	Primary ferrous metal products, Petroleum refineries, Storage batteries
Lead	Storage batteries, Ammunition, Broadcast and wireless communications equipment
Lithium	Ceramics, Batteries, Aluminum production
Lutetium	Electromedical apparatus, Communications, energy wires and cables, Semiconductors and electron tubes
Magnesium	Broadcast and wireless communications equipment, Metal cans, boxes and other containers, Primary nonferrous metal smelting and refining
Manganese Dioxide Battery Grade Natural	None
Manganese Dioxide Battery Grade Synthetic	Primary batteries
Manganese, Ferro	Aircraft engines and engine parts, Motor vehicle parts, Ship building and repairing

Table 2-3. Important Defense Uses of Strategic Materials (continued)

Material	Important Defense Uses
Manganese Metal, Electrolytic	Broadcast and wireless communications equipment, Metal cans, boxes and other containers, Aircraft
Manganese Ore, Chemical and Metallurgical Grades	Primary ferrous metal products, Primary aluminum production, Aluminum products
Mercury	Basic inorganic chemicals, Search, detection and navigation instruments, Wiring devices
Molybdenum	Aircraft, Missiles and space vehicles, Aircraft engines and engine parts
Neodymium	Magnets, Lasers, Capacitors
Nickel	Missiles and space vehicles, Aircraft, Motor vehicle parts
Palladium (Platinum Group)	Motor vehicle parts, Semiconductors and electron tubes, Electronic components
Platinum (Platinum Group)	Motor vehicles parts, Aircraft engines and engine parts, Computer storage devices
Praseodymium	Pigment, Ceramics, Fiber optics, Medical imaging, Alloying agent
Quartz Crystal	Electricity and signal testing, Other electronic components
Rhenium	Jet engines, Broadcast and wireless communications equipment, Petroleum refineries
Rhodium (Platinum Group)	Aircraft, Electrical machinery, Nuclear reactors
Rubber	Tires, gaskets, packing and sealing devices
Ruthenium	Wiring devices, Semiconductors and electron tubes, Basic inorganic chemicals
Samarium	Neutron absorber for nuclear reactors, Lasers, Magnets, Capacitors
Scandium	Electric lamp bulbs and parts, Petroleum refineries, Semiconductors and electron tubes, Other aircraft parts and equipment
Selenium	Primary ferrous metal products, Semiconductors and electron tubes, Glass products except containers, Primary aluminum production
Silicon	Primary aluminum production, Plastics materials and resins, Other basic organic chemicals
Silicon Carbide	Abrasive products, Motor vehicle parts, Broadcast and wireless communications equipment

Table 2-3. Important Defense Uses of Strategic Materials (concluded)

Material	Important Defense Uses
Silver	Search, detection and navigation instruments, Broadcast and wireless communications equipment, Photographic films and chemicals
Strontium	Other chemical products, Primary nonferrous metal smelting and refining, Nonferrous metal foundries
Tantalum	Electronic components, Aircraft engines and engine parts, Surgical appliances and supplies
Tellurium	Nonferrous metal products, except copper and aluminum, Basic inorganic chemicals, Industrial gas
Terbium	Lasers, Phosphors for lighting and displays, Magnets, Magnet or restrictive alloys
Thulium	Semiconductors and electron tubes, Other electronic components, Irradiation apparatus, Wiring devices
Tin	Electronic components, Metal coating, engraving, heat treating and allied activities, Architectural and structural metal products
Titanium Sponge	Precursor to titanium alloys used in Aircraft, Missiles and space vehicles, Aircraft engines and engine parts
Tungsten	Search, detection and navigation instruments, Aircraft, Broadcast and wireless communications equipment
Vanadium	Ship building and repairing, Motor vehicle parts, Aircraft
Ytterbium	Communications, energy wires and cables, Semiconductors and electron tubes, Primary ferrous metal products, Irradiation apparatus
Yttrium	Displays and lighting
Zinc	Motor vehicle parts, Shipbuilding and repairing, Miscellaneous fabricated metal products
Zirconium Metal	Missiles and space vehicles, Aircraft engines and engine parts, Turbine and turbine generator set units, Nuclear fuel assemblies
Zirconium Ores and Concentrates	Aircraft engine and engine parts, Metal coating, engraving, heat treating and allied activities, Industrial mold manufacturing

Appendix 3
Base Case Assumptions and Requirements
(Unclassified)

Introduction

This appendix provides an overview of the 2013 National Defense Stockpile (NDS) Requirements Report Base Case. It is in four separate parts.

- The first part presents an overview of the Base Case conflict scenario, at an unclassified level. For further information on the scenario, the reader should refer to Appendix 4, which provides classified details.
- The second part discusses in some detail the Base Case assumptions about supplies of materials. (The methodology description in Appendix 7 provides context on how the modeling process interprets and makes use of these assumptions.)
- The third part describes the Base Case assumptions about demands for goods, services, and materials. (Again, Appendix 7 may be helpful.)
- Finally, the fourth part lists some information about the Base Case that is required by law.

The 2013 Requirements Report Base Case assumptions, on both the demand side and the supply side, were reviewed and approved by an Office of the Secretary of Defense/Joint Staff advisory panel in January 2012. This report is based on current databases for all key information employed to estimate NDS requirements.

Overall Scenario Description

Section 14 of the Stock Piling Act mandates that NDS requirements be founded on a Base Case that includes: (1) a military conflict scenario consistent with the scenario used by the Secretary of Defense in budgeting and defense planning purposes; (2) those materials necessary to replenish or replace, within three years of the end of the conflict scenario, all munitions, combat support items, and weapon systems that would be required after such a military conflict; (3) all other essential military demands; and (4) all essential industrial and civilian sector demands (see Appendix 1).

For purposes of the current study, the 2013 NDS Requirements Report Base Case builds upon the best available DoD-approved analytic scenario products. Consistent with the Stock Piling Act, the defense planning scenarios approved by DoD for use in this study are aligned with the force planning framework articulated in DoD's latest National Defense Strategy.[1] Every effort was made to conform closely to the Force Sizing Construct, including examination of multiple contingencies occurring more or less concurrently during the conflict year. These contingencies consisted of combinations of scenarios involving: (1) response to a catastrophic attack in the U.S.; (2) deterring and defeating two regional aggressors; (3) deterring and defeating a highly capable aggressor; and (4) responding to several significant counter-insurgency activities. (See classified Appendix 4.) The conflict parts of the Base Case scenario have been developed in coordination with the Office of the Under Secretary of Defense for Policy to ensure consistency with the strategic guidance.

Supply-Side Assumptions for the Base Case

U.S. Production, Capacity, and Ramp-up

U.S. material producers operating at less than full capacity could increase output to mobilization levels (full production within existing capacity) during a contingency. The United States is assumed to be able to obtain all of the current output and any increased output. The Base Case assumes that during the first six months of the first scenario year, the United States may acquire the estimated production from U.S. producers. After the first six months of the scenario, the United States is assumed to be able to acquire the full-capacity output of U.S. producers. This is consistent with an assumption that moving to mobilization levels will take about six months—to obtain all necessary additional skilled labor, production equipment, permits and funding. The national emergency posited in the Base Case postulates that all necessary funding will be made available by the U.S. government to achieve these levels of production. This is a change in assumption from the 2011 NDS Requirements study, where full capacity was assumed available only after twelve months.[2]

Note that the U.S. supply does *not* include any inventory that might be in the NDS. The idea is to determine whether available material supply—under the Base Case assumptions, without any mitigation measures applied—is sufficient to offset material demand. If it is not, various mitigation measures, including stockpiling, are considered.

1 See *The National Defense Strategy*, Department of Defense, 2012.

2 The reason for this reduction in ramp-up time is as follows. The U.S. Geological Survey refined its definitions and data on ramp-up with the result that the capacities in the Base Case are estimated to be achievable within several months. Six months was selected as a prudent parameter. This revision was endorsed by the DoD steering group for the study.

Foreign Production, Capacity, and Ramp-up

Foreign material producers operating at less than full capacity could increase output to mobilization levels (full production within existing capacity) during a contingency. Depending on the extent of global shortages and competition for supplies, the United States is assumed to be able to obtain its normal market share of any increased output (subject to adjustments for reliability, war damage, and shipping losses, as mentioned below). The Base Case assumes that during the first six months of the first scenario year, the United States may acquire its normal market share of estimated reliable, undamaged foreign production from countries that are not enemy combatants. After the first six months of the scenario, the United States is assumed to be able to acquire its normal share of full-capacity output. As with U.S. supply, this is consistent with an assumption that moving to full capacity mobilization levels will take, on average, about six months to obtain all necessary additional skilled labor, production equipment, permits and funding. The national emergency posited in the Base Case postulates that all necessary funding will be made available by the U.S. government to achieve these levels of production. In contrast, the 2011 NDS Requirements study assumed that full foreign capacity was available only after twelve months.[3]

Secondary U.S. Supply

Secondary U.S. supply (i.e., recycled material) is assumed to be available in the amounts indicated in the databases, and is assumed to be capable of offsetting defense (and emergency investment) demands, as well as civilian demands.[4] It is believed that in a national emergency reprocessing capability, rather than availability of scrap feedstock, will be the tightest factor in determining the amount of usable secondary supply. The USGS secondary supply data are for reprocessing capacity.

Concerted Programs

Concerted programs represent potential material production facilities that are not currently in operation, but could be brought online after a period of time if a certain (possibly large) amount of money were invested in them. Such programs might include restarts of dormant facilities, expansions at existing facilities, or construction of new facilities. However, the 2013 Base Case assumes that concerted programs will *not* be available: it only assumes the availability of mining capability that is already active or that is currently expected to become active during the Base Case time frame, whether U.S. or foreign. Without significant pre-planning and contingency contract

---

[3] The same argument applies here as to U.S. supply (previous footnote).

[4] See the first part of Appendix 7 for the definitions of the three categories of demand: defense, emergency investment (industrial), and civilian.

arrangements, the timelines for activating concerted programs are assumed to be too long to be relevant for Base Case assessments.

Supply from Combat Adversaries (enemy combatants)

Enemy combatant states will not be considered available to supply materials, goods, and services to the United States for a period of time surrounding the conflict, due to some combination of enemy embargoes, U.S. sanctions, and potential war damage. The Base Case assumes that the no-supply period lasts for a year; and during that year, their supplies simply are unavailable to the United States.[5] The availability of such supplies in subsequent years is assumed to be a function of the particular country's infrastructure reliability, lingering anti-U.S. sentiment, and other relevant scenario considerations mentioned in this section.

Supply from Unwilling Countries (anti-U.S. sentiment)

Some foreign governments, not necessarily directly involved in combat, may be judged partially or completely *unwilling* to supply materials to the United States as a result of the contingency. The United States is assumed in the Base Case to eventually obtain its normal share of the "unwilling fraction" of those materials even from unwilling sources by dealing with third parties on global markets. However, such indirect acquisitions will be subject to non-trivial delays. For the Base Case, the delay for subject materials is assumed to be six months. The proportion of a country's materials deemed unreliable due to unwillingness (and thus subject to a delay) depends on the degree of its hostility, as indicated by a score assigned to that country by reliability raters at the Defense Intelligence Agency (DIA) (see Appendix 15).

Foreign Infrastructure/Ability Reliability Factors

Some foreign economies, not necessarily directly involved in combat in the Base Case, may be judged more or less unable to supply the quantity of materials that they might normally provide based on their current production and production capacities. Thus, they may prove unreliable as a result of scenario-specific levels of political instability, labor unrest, or breakdowns in transportation or power infrastructures. (Note that foreign infrastructure reliability is a separate source of decrement than war damage itself.) Such scenario-specific problems are estimated by reliability raters at DIA. The raters assign a proportion (0 to 100 percent) of a country's anticipated material output that is assumed to be lost due to this factor. See Appendix 15 for more details.

---

[5] The no-supply period is influenced by political and economic factors and need not coincide exactly with the period of combat.

War Damage Factors

Countries involved in the conflict are subject to war damage that might affect their ability to produce materials, goods, and services. Reduction factors to model war damage are set to be consistent with the particulars of the conflict scenario. See classified Appendix 4 for details.

Shipping Loss Factors

Material and goods from certain countries might be subject to losses in transit due to attack from enemy countries. Reduction factors to model this depend on the country of origin, and are set to be consistent with the particulars of the conflict scenario. See classified Appendix 4 for details.

U.S. Share of Foreign Supplies ("market share")

Another input to the requirements estimation process is the share of foreign material supplies that the United States can expect to acquire. Other countries, especially our allies and friends, will need a portion of available materials to meet their needs; and unfriendly countries may still be able to outbid the United States on world markets for materials. Accordingly, the Base Case limits the U.S. share of the scenario-specific estimates of reliable foreign production to the larger of two measures: (1) its current share of foreign production; and (2) its share of the combined gross domestic products (GDPs) of the countries that demand the material. (GDP is considered a measure of ability to bid for material. Other things being equal, the larger the U.S. GDP is relative to the GDPs of other countries that demand the material, the more material for which the United States can successfully bid.). This regular share operates in addition to the conflict-related decrement factors.

In the Base Case, only the regular share of foreign supplies, as indicated above, is allowed. A possible shortfall mitigation strategy is to arrange for the United States to purchase an extra share of foreign production that corresponds to currently unused capacity. See Appendix 10 for details.

Usability of Supply to Satisfy Defense Demand (market dominators)

The modeling process allows certain foreign material supply to be precluded from satisfying defense and emergency investment demands. (It can be used to satisfy essential civilian demand.) A number of input factors govern exactly which kinds of foreign supply are assumed to be capable of offsetting defense demand.

In the 2013 Base Case, available foreign supply (after all the relevant decrements mentioned above have been applied) is allowed to offset defense demand—unless the material comes from a country that is a "market dominator," defined as a foreign country that produces more than half of the global production of that material.[6] As in past Requirements Reports, the 2013 Base Case assumption is that a market dominator's production may not be counted upon by the United States to meet defense (and emergency investment) demands. The reason for this is the belief that it is especially risky to depend upon supplies from a single foreign source rather than from a variety of such sources, given the greater potential for accidents, natural disasters, or deliberate sabotage, not otherwise explicitly accounted for in the scenario, to disrupt a single source by comparison with multiple sources. Such dependence on a single source is assumed in the 2013 Base Case to be unacceptably risky in regard to meeting defense demands. An alternative plausible assumption could extend this restriction to essential civilian demands as well. Of course, if a Base Case scenario were to actually happen and market dominators were able and willing to supply materials for defense, so much the better.

Demand-Side Assumptions for the Base Case

Overall, the 2013 Requirements Report Base Case demands for essential goods and services are projected on a time-phased basis for all military, industrial, and essential civilian uses of strategic and critical materials under the specified scenario. For the 2013 Requirements Report Base Case, this means projections postulated for the conflict year (2015) and each of the three regeneration years (2016–18). Some of the specifics are discussed below.

Economic Growth

The study projects future U.S. demands for strategic and critical materials based, in part, on an official recent forecast of the U.S. economy. The Base Case utilizes the long-term macroeconomic forecast prepared by the President's Council of Economic Advisors (CEA) and released as part of the Economic Report of the President in February 2012. This official forecast is used by the Administration to support policy and budgetary deliberations.

Defense Demand

Demand for goods and services used by the defense sector consists of two parts. The first part corresponds to regular, ongoing defense budget. Demands upon each of 360 sectors of the U.S. economy are estimated using special economic forecasting models from the Inter-industry Forecasting Project at the University of Maryland (INFORUM). (See Appendix 7 for more information.) The inputs to these models are set to be consistent with the Future Years Defense Program (FYDP) for fiscal years 2015 through

[6] The computation of the fraction of world supply that a specific country provides is made before any of the conflict-related decrements are applied to its supply level.

2018. The second part corresponds to goods and services needed to rebuild key weapons lost and consumed in the postulated Base Case conflict scenario. These demands are estimated using data from the Assistant Secretary of Defense for Cost Assessment and Program Evaluation, as well as information from INFORUM. All defense demands are considered essential.

Essential Civilian Demand

Demand for goods and services used by the civilian sector are projected over the scenario period (2015 through 2018) using the economic forecasting models from the INFORUM organization. The inputs to these models are set to be consistent with the CEA's forecast of the economy for that period, as mentioned above.

Consistent with past reports, this report assumes that the preponderance of these civilian demands for goods and services will need to be met. At the same time, the Base Case makes reductions in the projected demand for some goods and services for the civilian sector in order to preclude stockpiling for items that would be considered nonessential during the conflict and regeneration period. These reductions in civilian demands are consistent with the Stock Piling Act requirement that only essential civilian needs should be taken into account when determining how much material should be stockpiled. In this regard, this report does not assume that the Federal Government would necessarily impose wide and detailed regulations to ration nonessential goods and services during the four-year scenario period. The market economy might provide these goods and services at the level estimated in the peacetime forecast.[7] However, consistent with the statutory guidance, the NDS will not be structured to ensure the availability of nonessential items by stockpiling materials for their production.

The study uses certain factors to determine the portion of projected civilian demand that should be considered essential and thus be included in the essential demands for the Base Case. The factors are less stringent in the first (combat/conflict) year than in the subsequent three years of regeneration. Appendix 14 provides details on these factors and how they are developed.

Imports and Exports

The economic forecasting models from the University of Maryland (see Appendix 7), which forecast defense demand and civilian demand for goods and services, also forecast imports and exports of goods and services (for each of 360 different sectors of the economy), under peacetime (baseline, steady-state) conditions. Goods produced for

---

[7] This might happen in several ways. For example, manufacturers might employ less material-intensive substitutes (such as plastic and glass instead of aluminum). Or more end-use goods, such as cars and electronics, could be imported, rather than produced here.

export constitute a source of material demand (the materials needed to produce these goods). Conversely, materials contained in imports of finished goods lessen the demand for the materials needed to produce such goods domestically. When computing the material demand that the U.S. government needs to address via stockpiling or other mitigation measures, the modeling process considers some portion of the material amounts associated with imports and exports.

The portion considered can be adjusted to be concordant with the national emergency scenario. This is modeled by decrementing the forecasted imports and exports of goods and services, and then using these decremented values when computing material demand from industrial demand (see Appendix 7). The decrement factors vary by sector of the economy. Imports are decremented in the Base Case to take into account the unreliabilities of the particular countries of origin. Imports of goods from adversary countries are considered unavailable for the first year of the scenario. Exports are decremented judgmentally to reflect the fact that in a national emergency, the United States might need some of the goods that would otherwise be exported, or might need the material used to produce these goods, or might not want to guarantee government coverage for that material. In the Base Case, for most sectors of the economy, exports of goods and services are set to 85 percent of their forecasted peacetime values, in all years of the scenario.

Homeland Recovery

A catastrophic attack on a major U.S. city by a foreign terrorist organization or rogue state would cause substantial destruction of fixed assets and consumer durables. The Base Case assumes that such an attack does occur in the first scenario year, and that (based on a structured estimation process) a homeland recovery program to replace lost assets would require a total of at least $100 billion in private and government spending over the three regeneration years. These recovery demands are treated as essential. They are apportioned between the defense and essential civilian demand sectors for estimation and tracking purposes in this study.

Report Required by Section 14(b) of Stock Piling Act: National Emergency Planning Assumptions

Section 14(b) of the Stock Piling Act directs that the DoD describe the content of a number of specified national emergency planning assumptions used to estimate requirements for NDS. Information on each of the planning assumptions mentioned in section 14(b) is provided below.

Length of Assumed Emergency

The military conflict for which material requirements are calculated lasts for roughly one year. (See Classified Appendix 4 for details.)

Intensity of Conflict

(See Classified Appendix 4.)

Military Force Structure to Be Mobilized

The scenario assumes that the warning time is too short to build new forces and that the United States has sufficient existing forces to meet the requirements for defeating the enemy.

Losses from Enemy Action

(See Classified Appendix 4.)

2013 Base Case Demand for 72 Strategic and Critical Materials (Military Demands)

The 2013 Base Case scenario considers: a catastrophic attack on a U.S. city by a foreign terrorist organization or rogue state; the worst case by mission area of several specified major overseas (state vs. state) conflicts; and ongoing foundational activities, including deterrence, forward presence, and building partner capacity. In the 2013 Base Case, the United States plans to continue with its regular Fiscal Year 2015–2018 FYDP acquisitions as well as to regenerate key weapon systems and munitions lost after the short-warning major conflict and other contingencies. (See Classified Appendix 4.)

Of the 72 non-proprietary strategic and critical materials assessed in this Base Case, the dollar value of those that are needed over the four-year Base Case scenario for the manufacture of goods and services in the military sector is $15.2 billion in 2012 dollars. The 2013 Base Case demand by this military sector represents approximately 4.3 percent of the overall four-year Base Case scenario demand ($352 billion) for these 72 materials.[8]

2013 Base Case Demand for 72 Strategic and Critical Materials (Industrial Demands)

The industrial, or emergency investment, sector is limited to materials needed to meet requirements for new plant and equipment to overcome any capacity shortfalls caused by accelerated production of defense goods during the four-year emergency scenario period. Of the strategic and critical materials assessed, the value of those needed

[8] See Appendix 7 for a description of the methodology used in calculating these demands.

in the economy for the manufacture of goods and services for this purpose is $0.7 billion (2012 dollars).

2013 Base Case Demand for 72 Strategic and Critical Materials (Essential Civilian Demands)

Of the 72 non-proprietary materials assessed in the Base Case, the dollar value of those 72 materials that are needed over the four-year scenario period in the economy for the manufacture of essential goods and services for the civilian sector is $336.3 billion (2012 dollars). Demand by this sector represents approximately 95.5 percent of the overall Base Case scenario demand ($352 billion) for these 72 materials.

Available Foreign Supplies with Adjustments

The available supplies of strategic and critical materials from foreign sources are defined as those expected to be available to the United States during the military conflict year, and the subsequent regeneration period—after accounting for supplier country reliability, the U.S. market-share, supplier country war damage, shipping losses, and "market dominator" criteria. (See the second section of this appendix for discussion of these criteria.) The list of such supplies available during the roughly one year of mobilization and military conflict and each year of regeneration can be provided upon request.

Domestic Production of Materials

Total domestic production levels are estimated for strategic and critical materials during the roughly one year of military conflict and three years of regeneration. The estimates can be provided upon request.

Civilian Austerity Measures

The Base Case scenario assumes that the Federal Government will not necessarily take any regulatory measures to curtail or prevent the production of nonessential civilian goods and services. Nevertheless, there are decrements imposed on normal projected CEA civilian sector demands for the period. These are decrements imposed to eliminate nonessential civilian goods and services, in accordance with the requirements of the Stock Piling Act. These decrements are based on the advice of a civilian sector working group and are described in Appendix 14.

Appendix 4
Classified Description of the Base Case
(Classified Information available under separate cover)

Appendix 5
Assessment of Proprietary-Level Materials
(Proprietary Information available under separate cover)

Appendix 6
Material Shortfalls and Related Information

Material Shortfalls

For the 72 non-proprietary materials, a comparison of projected demand with projected available supply was performed, following the methodology described in Appendix 7, using the National Defense Stockpile (NDS) Base Case assumptions laid out in Appendix 3. Of the 72 materials, 19 showed shortfalls. These are listed in Table 6-1, arranged by category. Amounts are shown both in the indicated mass units and in millions of dollars. The dollar valuations were computed using material prices current as of March 31, 2012.

Table 6-1 includes an amount of 52 short tons of beryllium metal, valued at $16.1 million. The supply-demand comparison did not find a shortfall for beryllium metal, but the underlying data assumed that the sole U.S. supplier would be fully in production by the starting scenario year, 2015. To allow for the possibility that this would not be the case, DoD recommends that 52 short tons of beryllium metal be stockpiled. This amount is approximately equal to two years' worth of defense demand. It is to be considered a defense related shortfall.

The supply-demand comparison found shortfalls for 18 materials. All of these shortfalls occur in the first year of the four-year scenario; there are no shortfalls in subsequent years. Also, all shortfalls represent unmet civilian demands: given the assumptions of the modeling process, there is enough supply available to completely offset defense and emergency investment demands.[1] All in all, 19 materials in Table 6-1 exhibit nonzero amounts: the 18 shortfalls found via the supply-demand comparison analysis, plus the extrinsically specified goal for beryllium metal.

[1] As in the 2011 Base Case, supply from countries that dominated the market was not allowed to offset defense or emergency investment demand. This restriction was imposed to guard against the unreliability intrinsically associated with a concentrated supply source. A country was considered to dominate the market for a given material if that country provided more than 50 percent of the world supply of that material. Although there are a number of dominant supplier countries, available supply from non-dominator countries was sufficient to offset defense and emergency investment demands.

Table 6-1. Base Case Shortfalls for Materials Examined in the 2013 NDS Study

Material Name	Units[a]	Base Case Shortfalls	
		in Units	in $M[b]
Metals (28)			
Aluminum Metal	ST	0	$0.00M
Antimony	ST	22,575	$182.04M
Beryllium Metal	ST	52	$16.12M
Bismuth	LB	3,629,659	$39.59M
Cadmium	LB	0	$0.00M
Chromium Metal	ST	718	$10.68M
Cobalt	LB Co	0	$0.00M
Columbium	LB Cb	0	$0.00M
Copper	ST	0	$0.00M
Gallium	KG	17,686	$10.48M
Germanium	KG	28,888	$35.66M
Hafnium	MT	0	$0.00M
Indium	Tr Oz	0	$0.00M
Lead	ST Pb	0	$0.00M
Lithium	MT	0	$0.00M
Magnesium	MT	0	$0.00M
Manganese Metal, Electrolytic	ST	7,406	$22.96M
Mercury	LB	0	$0.00M
Molybdenum	LB	0	$0.00M
Nickel	ST Ni	0	$0.00M
Strontium	MT Sr	0	$0.00M
Tantalum	LB Ta	623,307	$42.07M
Tin	MT	19,428	$416.09M
Titanium Sponge	ST	0	$0.00M
Tungsten	LB W	11,288,268	$84.26M
Vanadium	ST V	0	$0.00M
Zinc	ST	0	$0.00M
Zirconium Metal	ST	0	$0.00M
Subtotal: Metals			**$859.95M**
Precious Metals (7)			
Iridium (Platinum Group)	Tr Oz	0	$0.00M
Palladium (Platinum Group)	Tr Oz	0	$0.00M
Platinum (Platinum Group)	Tr Oz	0	$0.00M
Rhenium	LB	0	$0.00M
Rhodium (Platinum Group)	Tr Oz	0	$0.00M
Ruthenium (Platinum Group)	Tr Oz	0	$0.00M
Silver	Tr Oz	0	$0.00M
Subtotal: Precious Metals			**$0.00M**

Table 6-1. Base Case Shortfalls for Materials Examined in the 2013 NDS Study (continued)

Material Name	Units[a]	Base Case Shortfalls	
		in Units	in $M[b]
Ores and Compounds (11)			
Aluminum Oxide Fused Crude	ST	231,485	$131.67M
Bauxite Metal Grade Jamaica & Suriname	LDT	0	$0.00M
Bauxite Refractory	LCT	0	$0.00M
Beryl Ore	ST	0	$0.00M
Chromite, Chemical, Refractory, and Metallurgical Grade Ore	SDT	0	$0.00M
Fluorspar, Acid Grade	SDT	56,322	$21.54M
Fluorspar, Metallurgical Grade	SDT	0	$0.00M
Manganese Dioxide Battery Grade Natural	SDT	0	$0.00M
Manganese Dioxide Battery Grade Synthetic	SDT	0	$0.00M
Manganese Ore, Chemical & Metallurgical Grades	SDT	0	$0.00M
Zirconium Ores and Concentrates	SDT	0	$0.00M
Subtotal: Ores and Compounds			**$153.21M**
Miscellaneous Non-Metals (7)			
Boron	MT oxide	0	$0.00M
Quartz Crystals (synthetic)	LB	0	$0.00M
Rubber (natural)	LT	0	$0.00M
Selenium	KG	0	$0.00M
Silicon	MT	0	$0.00M
Silicon Carbide	ST	81,869	$93.88M
Tellurium	MT	0	$0.00M
Subtotal: Miscellaneous Non-Metals			**$93.88M**
Alloys (3)			
Beryllium Copper Master Alloy	ST	0	$0.00M
Chromium, Ferro	ST	0	$0.00M
Manganese, Ferro	ST	0	$0.00M
Subtotal: Alloys			**$0.00M**

Table 6-1. Base Case Shortfalls for Materials Examined in the 2013 NDS Study (concluded)

Material Name	Units[a]	Base Case Shortfalls	
		in Units	in $M[b]
Rare Earths (16)			
Cerium	MT oxide	0	$0.00M
Dysprosium	MT oxide	47	$21.64M
Erbium	MT oxide	124	$12.43M
Europium	MT oxide	0	$0.00M
Gadolinium	MT oxide	0	$0.00M
Holmium	MT oxide	0	$0.00M
Lanthanum	MT oxide	0	$0.00M
Lutetium	MT oxide	0	$0.00M
Neodymium	MT oxide	0	$0.00M
Praseodymium	MT oxide	0	$0.00M
Samarium	MT oxide	0	$0.00M
Scandium	KG oxide	572	$0.77M
Terbium	MT oxide	7	$7.16M
Thulium	MT oxide	20	$3.31M
Ytterbium	MT oxide	0	$0.00M
Yttrium	MT oxide	1,899	$85.17M
Subtotal: Rare Earths			**$130.48M**
Total: All 72 Materials			**$1,237.52M**

a. See Appendix 17 for definitions of the abbreviations used for material units.

b. In March 31, 2012 dollars/prices. Dollar valuations for materials with inventory in the stockpile represent "realizable stockpile values" as of March 31, 2012, and might be higher or lower than the current market value.

Comparison with 2011 Requirements Report Results

Of the 72 materials, 58 were also studied for the 2011 Requirements Report. The shortfalls for these materials can be compared for the 2013 and 2011 case. Note that, as described in Appendix 3, one key change in assumptions was made between the 2011 and 2013 Base Cases. This concerned the length of time it would take materials producers (U.S. and foreign) to ramp up to full capacity. The 2011 study assumed a year of ramp-up time, while the 2013 study assumes six months. It is instructive to compare the 2013 Base Case shortfalls with a 2011 sensitivity case that assumed a six-month ramp-up time but otherwise had same assumptions as the 2011 Base Case. Total dollar results for all three cases (evaluated with the 2013 study prices) are shown in Table 6-2.

Table 6-2. Comparison of Total Shortfall Dollar Values, 2013 vs. 2011 Study

Case	Materials (of 58) with Shortfall	Total Shortfall for 58 Materials ($M, using March 31, 2012 prices)
2013 Base Case (six-month ramp-up)*	18	$1,205
2011 Base Case (twelve-month ramp-up)	27	$2,833
2011 Case with six-month ramp-up	21	$2,041

*Does not include the extrinsically specified beryllium metal goal.

It is evident that the shortfall for the 2013 Base Case is considerably lower than not only the 2011 Base Case shortfall but also the shortfall in the 2011 case with six-month ramp-up. One possible reason for this is that the 2013 Base Case scenario is set several years later (2015 through 2018, as opposed to 2011 through 2014 for the 2011 Base Case). The supply data are consistent with an assumption that a number of U.S. suppliers just coming on board in 2011 are fully operational by 2015.

Material Inventories, Shortages, and Surpluses

Of the 72 non-proprietary materials studied, the NDS currently has on hand inventory for 17 of them. Table 6-3 shows their NDS inventory as of June 30, 2012, evaluated with the study prices. Table 6-4 shows the material shortages—defined as shortfalls minus NDS inventory—and surpluses. Of the 19 materials with shortfalls, 13 have no NDS inventory at all (so the shortfall equals the shortage), three (germanium, tantalum, and tin) have some NDS inventory, but not enough to cover the shortfall, and three (beryllium metal, chromium metal, and tungsten) have sufficient NDS inventory to cover the shortfall.[2] In addition, there is inventory for 11 materials that do not show shortfalls in the study.

The surpluses and shortages shown in Table 6-4 are the results of simple subtraction and are essentially for informative purposes. They are not the basis of the shortfall mitigation results reported in Figures 4 through 9 of the main document. The results in the main document take into account other possible shortfall mitigation measures, in addition to stockpiling, and apply probabilities of success to each measure. Appendix 11 provides the details.

[2] As discussed in Appendix 3, the supply-demand comparison that underlies the shortfall computation does not include existing NDS inventory in the supply.

Table 6-3. Materials Examined in the 2013 NDS Study, with Current NDS Inventories

Material Name	Units[a]	NDS Inventory, June 30, 2012	
		in Units	in $M[b]
Metals (28)			
Aluminum Metal	ST	0	$0.00M
Antimony	ST	0	$0.00M
Beryllium Metal[c]	ST	99	$30.54M
Bismuth	LB	0	$0.00M
Cadmium	LB	0	$0.00M
Chromium Metal	ST	4,512	$67.14M
Cobalt	LB Co	663,709	$15.53M
Columbium	LB Cb	22,156	$0.76M
Copper	ST	0	$0.00M
Gallium	KG	0	$0.00M
Germanium	KG	16,362	$20.20M
Hafnium	MT	0	$0.00M
Indium	Tr Oz	0	$0.00M
Lead	ST Pb	0	$0.00M
Lithium	MT	0	$0.00M
Magnesium	MT	0	$0.00M
Manganese Metal, Electrolytic	ST	0	$0.00M
Mercury[d]	LB	9,781,604	$0.00M
Molybdenum	LB	0	$0.00M
Nickel	ST Ni	0	$0.00M
Strontium	MT Sr	0	$0.00M
Tantalum	LB Ta	3,802	$0.26M
Tin	MT	4,020	$86.10M
Titanium Sponge	ST	0	$0.00M
Tungsten	LB W	35,125,753	$262.20M
Vanadium	ST V	0	$0.00M
Zinc	ST	7,992	$17.20M
Zirconium Metal	ST	0	$0.00M
Subtotal: Metals			**$499.92M**
Precious Metals (7)			
Iridium (Platinum Group)	Tr Oz	568	$0.36M
Palladium (Platinum Group)	Tr Oz	0	$0.00M
Platinum (Platinum Group)	Tr Oz	8,380	$12.60M
Rhenium	LB	0	$0.00M
Rhodium (Platinum Group)	Tr Oz	0	$0.00M
Ruthenium (Platinum Group)	Tr Oz	0	$0.00M
Silver	Tr Oz	0	$0.00M
Subtotal: Precious Metals			**$12.96M**

Table 6-3. Materials Examined in the 2013 NDS Study, with Current NDS Inventories (continued)

Material Name	Units[a]	NDS Inventory, June 30, 2012	
		in Units	in $M[b]
Ores and Compounds (11)			
Aluminum Oxide Fused Crude	ST	0	$0.00M
Bauxite Metal Grade Jamaica & Suriname	LDT	0	$0.00M
Bauxite Refractory	LCT	0	$0.00M
Beryl Ore[e]	ST	1	$0.00M
Chromite, Chemical, Refractory, and Metallurgical Grade Ore	SDT	0	$0.00M
Fluorspar, Acid Grade	SDT	0	$0.00M
Fluorspar, Metallurgical Grade	SDT	0	$0.00M
Manganese Dioxide Battery Grade Natural	SDT	0	$0.00M
Manganese Dioxide Battery Grade Synthetic	SDT	0	$0.00M
Manganese Ore, Chemical & Metallurgical Grades	SDT	322,025	$1.69M
Zirconium Ores and Concentrates	SDT	0	$0.00M
Subtotal: Ores and Compounds			**$1.69M**
Miscellaneous Non-Metals (7)			
Boron	MT oxide	0	$0.00M
Quartz Crystal[f]	LB	15,729	$0.19M
Rubber (natural)	LT	0	$0.00M
Selenium	KG	0	$0.00M
Silicon	MT	0	$0.00M
Silicon Carbide	ST	0	$0.00M
Tellurium	MT	0	$0.00M
Subtotal: Miscellaneous Non-Metals			**$0.19M**
Alloys (3)			
Beryllium Copper Master Alloy	ST	0	$0.00M
Chromium, Ferro	ST	162,330	$359.56M
Manganese, Ferro	ST	383,528	$531.78M
Subtotal: Alloys			**$891.33M**

Table 6-3. Materials Examined in the 2013 NDS Study, with Current NDS Inventories (concluded)

Material Name	Units[a]	NDS Inventory, June 30, 2012	
		in Units	in $M[b]
Rare Earths (16)			
Cerium	MT oxide	0	$0.00M
Dysprosium	MT oxide	0	$0.00M
Erbium	MT oxide	0	$0.00M
Europium	MT oxide	0	$0.00M
Gadolinium	MT oxide	0	$0.00M
Holmium	MT oxide	0	$0.00M
Lanthanum	MT oxide	0	$0.00M
Lutetium	MT oxide	0	$0.00M
Neodymium	MT oxide	0	$0.00M
Praseodymium	MT oxide	0	$0.00M
Samarium	MT oxide	0	$0.00M
Scandium	KG oxide	0	$0.00M
Terbium	MT oxide	0	$0.00M
Thulium	MT oxide	0	$0.00M
Ytterbium	MT oxide	0	$0.00M
Yttrium	MT oxide	0	$0.00M
Subtotal: Rare Earths			**$0.00M**
Total: All 72 Materials			**$1,406.10M**

a. See Appendix 17 for definitions of the abbreviations used for material units.

b. In March 31, 2012 dollars. Dollar valuations represent “realizable stockpile values” as of March 31, 2012, 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.

c. Beryllium metal. The inventory encompasses 7 tons of vacuum-cast metal plus 92 tons of hot-pressed powder.

d. Mercury. This report projects that the realizable stockpile value of the NDS mercury inventory is zero although other parties continue to trade in this commodity.

e. Dollar valuation of beryl ore inventory is zero to two decimal places.

f. The NDS inventory is for natural quartz crystal. The study examined demand and supply of synthetic industrial quartz crystal. No shortfall was found, but if one existed, it is unclear if the NDS inventory could ameliorate it.

Table 6-4. Base Case NDS Inventory Surpluses or Shortages (in parentheses) for Materials Examined in the 2013 NDS Study[a]

Material Name	Units[b]	Inventory		NDS Surplus (Shortage)	
		in Units	in $M[c]	in Units	in $M[c]
Metals (28)					
Aluminum Metal	ST	0	$0.00M	0	$0.00M
Antimony	ST	0	$0.00M	(22,575)	($182.04M)
Beryllium Metal[d]	ST	99	$30.54M	47	$14.42M
Bismuth	LB	0	$0.00M	(3,629,659)	($39.59M)
Cadmium	LB	0	$0.00M	0	$0.00M
Chromium Metal	ST	4,512	$67.14M	3,794	$56.46M
Cobalt	LB Co	663,709	$15.53M	663,709	$15.53M
Columbium	LB Cb	22,156	$0.76M	22,156	$0.76M
Copper	ST	0	$0.00M	0	$0.00M
Gallium	KG	0	$0.00M	(17,686)	($10.48M)
Germanium	KG	16,362	$20.20M	(12,526)	($15.46M)
Hafnium	MT	0	$0.00M	0	$0.00M
Indium	Tr Oz	0	$0.00M	0	$0.00M
Lead	ST Pb	0	$0.00M	0	$0.00M
Lithium	MT	0	$0.00M	0	$0.00M
Magnesium	MT	0	$0.00M	0	$0.00M
Manganese Metal, Electrolytic	ST	0	$0.00M	(7,406)	($22.96M)
Mercury[e]	LB	9,781,604	$0.00M	9,781,604	$0.00M
Molybdenum	LB	0	$0.00M	0	$0.00M
Nickel	ST Ni	0	$0.00M	0	$0.00M
Strontium	MT Sr	0	$0.00M	0	$0.00M
Tantalum	LB Ta	3,802	$0.26M	(619,505)	($41.81M)
Tin	MT	4,020	$86.10M	(15,408)	($329.99M)
Titanium Sponge	ST	0	$0.00M	0	$0.00M
Tungsten	LB W	35,125,753	$262.20M	23,837,485	$177.94M
Vanadium	ST V	0	$0.00M	0	$0.00M
Zinc	ST	7,992	$17.20M	7,992	$17.20M
Zirconium Metal	ST	0	$0.00M	0	$0.00M
Subtotal: Metals			**$499.92M**		**($642.34)**

Table 6-4. Base Case NDS Inventory Surpluses or Shortages (in parentheses) for Materials Examined in the 2013 NDS Study (continued)

Material Name	Units[b]	Inventory		NDS Surplus (Shortage)	
		in Units	in $M[c]	in Units	in $M[c]
Precious Metals (7)					
Iridium (Platinum Group)	Tr Oz	568	$0.36M	568	$0.36M
Palladium (Platinum Group)	Tr Oz	0	$0.00M	0	$0.00M
Platinum (Platinum Group)	Tr Oz	8,380	$12.60M	8,380	$12.60M
Rhenium	LB	0	$0.00M	0	$0.00M
Rhodium (Platinum Group)	Tr Oz	0	$0.00M	0	$0.00M
Ruthenium (Platinum Group)	Tr Oz	0	$0.00M	0	$0.00M
Silver	Tr Oz	0	$0.00M	0	$0.00M
Subtotal: Precious Metals			**$12.96M**		**$0.00M**
Ores and Compounds (11)					
Aluminum Oxide Fused Crude	ST	0	$0.00M	(231,485)	($131.67M)
Bauxite Metal Grade Jamaica & Suriname	LDT	0	$0.00M	0	$0.00M
Bauxite Refractory	LCT	0	$0.00M	0	$0.00M
Beryl Ore[f]	ST	1	$0.00M	1	$0.00M
Chromite, Chemical, Refractory, and Metallurgical Grade Ore	SDT	0	$0.00M	0	$0.00M
Fluorspar, Acid Grade	SDT	0	$0.00M	(56,322)	($21.54M)
Fluorspar, Metallurgical Grade	SDT	0	$0.00M	0	$0.00M
Manganese Dioxide Battery Grade Natural	SDT	0	$0.00M	0	$0.00M
Manganese Dioxide Battery Grade Synthetic	SDT	0	$0.00M	0	$0.00M
Manganese Ore, Chemical & Metallurgical Grades	SDT	322,025	$1.69M	322,025	$1.69M
Zirconium Ores and Concentrates	SDT	0	$0.00M	0	$0.00M
Subtotal: Ores and Compounds			**$1.69M**	0	**($153.21M)**
Miscellaneous Non-Metals (7)					
Boron	MT oxide	0	$0.00M	0	$0.00M
Quartz Crystals (synthetic)[g]	LB	15,729	$0.19M	15,729	$0.19M
Rubber (natural)	LT	0	$0.00M	0	$0.00M
Selenium	KG	0	$0.00M	0	$0.00M
Silicon	MT	0	$0.00M	0	$0.00M
Silicon Carbide	ST	0	$0.00M	(81,869)	($93.88M)
Tellurium	MT	0	$0.00M	0	$0.00M
Subtotal: Miscellaneous Non-Metals			**$0.19M**		**($93.88M)**

Table 6-4. Base Case NDS Inventory Surpluses or Shortages (in parentheses) for Materials Examined in the 2013 NDS Study (concluded)

Material Name	Units[b]	Inventory		NDS Surplus (Shortage)	
		in Units	in $M[c]	in Units	in $M[c]
Alloys (3)					
Beryllium Copper Master Alloy	ST	0	$0.00M	0	$0.00M
Chromium, Ferro	ST	162,330	$359.56M	162,330	$359.56M
Manganese, Ferro	ST	383,528	$531.78M	383,528	$531.78M
Subtotal: Alloys			**$891.33M**		**$0.00M**
Rare Earths (16)					
Cerium	MT oxide	0	$0.00M	0	$0.00M
Dysprosium	MT oxide	0	$0.00M	(47)	($21.64M)
Erbium	MT oxide	0	$0.00M	(124)	($12.43M)
Europium	MT oxide	0	$0.00M	0	$0.00M
Gadolinium	MT oxide	0	$0.00M	0	$0.00M
Holmium	MT oxide	0	$0.00M	0	$0.00M
Lanthanum	MT oxide	0	$0.00M	0	$0.00M
Lutetium	MT oxide	0	$0.00M	0	$0.00M
Neodymium	MT oxide	0	$0.00M	0	$0.00M
Praseodymium	MT oxide	0	$0.00M	0	$0.00M
Samarium	MT oxide	0	$0.00M	0	$0.00M
Scandium	KG oxide	0	$0.00M	(572)	($0.77M)
Terbium	MT oxide	0	$0.00M	(7)	($7.16M)
Thulium	MT oxide	0	$0.00M	(20)	($3.31M)
Ytterbium	MT oxide	0	$0.00M	0	$0.00M
Yttrium	MT oxide	0	$0.00M	(1,899)	($85.17M)
Subtotal: Rare Earths			**$0.00M**		**($130.48M)**
Total: All 72 Materials			**$1,406.10M**		**($1,019.9M)**

a. For materials where NDS inventory is insufficient to cover the shortfall, the net shortage is shown in parentheses. Total shortages, not including surpluses, appear at the bottom of each subgroup, and overall. Surpluses are shown without parentheses.

b. See Appendix 17 for definitions of the abbreviations used for the material units.

c. In March 31, 2012 dollars. Dollar valuations for materials with inventory in the stockpile represent "realizable stockpile values" as of March 31, 2012, and might be higher or lower than the current market value.

d. Beryllium metal. The inventory encompasses 7 tons of vacuum-cast metal plus 92 tons of HPP metal.

e. Mercury. This report projects that the realizable stockpile value of the NDS mercury inventory is zero although other parties continue to trade in this commodity.

f. Dollar valuation of beryl ore inventory is zero to two decimal places.

g. Quartz crystal. The NDS inventory is for natural quartz crystal. The study examined demand and supply of synthetic industrial quartz crystal. No shortfall was found, but if one existed, it is unclear if the NDS inventory could ameliorate it. Natural quartz crystal is used by industry to support the production of synthetic quartz.

Additional Information

Considerable additional information about the 2013 Base Case might be of interest. Two tables of results that may be especially informative are presented here.

Table 6-5 shows, for those materials with shortfalls, the shortfall as a percentage of the first year civilian demand. Equivalently, this is the percentage of first year civilian demand that is not met by available supply. Table 6-5 excludes the extrinsically specified goal for beryllium metal. For the other shortfall materials, the shortfall is all civilian and occurs all in the first year; thus, the percentages shown are in some sense the most pessimistic ones. The ratios of shortfall to total first year demand or the ratios shortfall to total scenario demand would be lower than those in Table 6-5.

Table 6-5. Shortfall to Demand Ratios for Materials with Shortfalls (Base Case)

Material	Units	Shortfall in Units	First Year Civilian Demand	Shortfall Percentage of First Year Civilian Demand
Aluminum Oxide Fused Crude	short tons	231,485	350,254	66.09
Antimony	short tons	22,575	34,937	64.62
Bismuth	pounds	3,629,659	7,029,463	51.63
Chromium Metal	short tons	718	9,180	7.82
Dysprosium	MT Oxide	47	247	19.01
Erbium	MT Oxide	124	153	81.08
Fluorspar Acid Grade	short tons	56,322	852,085	6.61
Gallium	kilograms	17,686	47,354	37.35
Germanium	kilograms	28,888	51,483	56.11
Manganese Metal--Electrolytic	short tons	7,406	29,375	25.21
Scandium	KG Oxide	572	924	61.93
Silicon Carbide	short tons	81,869	274,094	29.87
Tantalum	pounds Ta	623,307	2,602,992	23.95
Terbium	MT Oxide	7	55	13.05
Thulium	MT Oxide	20	24	83.16
Tin	metric tons	19,428	81,298	23.90
Tungsten	pounds W	11,288,268	41,563,047	27.16
Yttrium	MT Oxide	1,899	2,397	79.23

Table 6-6 displays the top foreign producers of the materials.

Table 6-6. Materials and Their Major Producing Countries

Material	Major Producing Countries
Aluminum Metal	China, Russia, United States
Aluminum Oxide Fused Crude	China, Germany, Brazil
Antimony	China, Bolivia, South Africa
Bauxite Metal Grade Jamaica & Suriname	Australia, China, Brazil
Bauxite Refractory	China, Russia, India
Beryl Ore	United States, China, Russia
Beryllium Copper Master Alloy	United States, Kazakhstan, China
Beryllium Metal	Kazakhstan, United States, China
Bismuth	China, Mexico, Australia
Boron	Turkey, United States, Argentina
Cadmium	China, South Korea, Kazakhstan
Cerium	China, United States, Australia
Chromite Ore (all grades)	South Africa, Kazakhstan, India
Chromium Ferro (Ferrochromium)	South Africa, China, Kazakhstan
Chromium Metal	Russia, France, United Kingdom
Cobalt	Congo (Kinshasa), Zambia, Australia
Columbium	Brazil, Canada, Malawi
Copper	Chile, Peru, United States
Dysprosium	China, Canada, Australia
Erbium	China, Canada, Australia
Europium	China, Australia, Canada
Fluorspar Acid Grade	China, Mexico, South Africa
Fluorspar Metallurgical Grade	China, Mexico, Mongolia
Gadolinium	China, Australia, Canada
Gallium	China, Germany, Kazakhstan

Table 6-6. Materials and Their Major Producing Countries (continued)

Material	Major Producing Countries
Germanium	China, Canada, Belgium
Hafnium	United States, France, China
Holmium	China, Canada, Australia
Indium	China, Japan, South Korea
Iridium (Platinum Group)	South Africa, Russia, United States
Lanthanum	China, United States, Australia
Lead	China, United States, Australia
Lithium	Australia, Chile, China
Lutetium	China, Canada, Australia
Magnesium	China, United States, Russia
Manganese Dioxide Battery Grade Natural	Brazil, China, Gabon
Manganese Dioxide Battery Grade Synthetic	China, United States, South Africa
Manganese Ferro (C and Si)	China, India, Ukraine
Manganese Metal Electrolytic	China, South Africa, Kazakhstan
Manganese Ore Chem/Metal Grade	South Africa, China, Australia
Mercury	Russia, Spain, China
Molybdenum	China, United States, Chile
Neodymium	China, Australia, United States
Nickel	Canada, Australia, Russia
Palladium (Platinum Group)	Russia, South Africa, United States
Platinum (Platinum Group)	South Africa, Russia, United States
Praseodymium	China, Australia, United States
Quartz Crystals (synthetic)	Russia, Japan, United States
Rhenium	Chile, United States, Kazakhstan
Rhodium (Platinum Group)	South Africa, Russia, Canada
Rubber (natural)	Thailand, Indonesia, Vietnam
Ruthenium (Platinum Group)	South Africa, Russia, Canada
Samarium	China, Australia, Canada
Scandium	China, Russia, Ukraine

Table 6-6. Materials and Their Major Producing Countries (concluded)

Material	Major Producing Countries
Selenium	China, United States, Russia
Silicon	China, Brazil, Norway
Silicon Carbide	China, Norway, Russia
Silver	Mexico, Peru, China
Strontium	China, Mexico, Germany
Tantalum	Egypt, Australia, Brazil
Tellurium	Russia, China, Japan
Terbium	China, Canada, Australia
Thulium	China, Canada, South Africa
Tin	China, Indonesia, Peru
Titanium (sponge)	China, Japan, Russia
Tungsten	China, United States, Australia
Vanadium	China, South Africa, Russia
Ytterbium	China, Canada, Sweden
Yttrium	China, Canada, South Africa
Zinc	China, Australia, Peru
Zirconium Metal	United States, France, China
Zirconium Ores & Concentrates	Australia, South Africa, China

Appendix 7
Shortfall Computation Methodology

Introduction

This appendix briefly describes the underlying methodology that is used to compute the material shortfall amounts reported in the main document and in Appendix 6. Considerable additional description of the methodology is available, at varying levels of detail, and can be provided upon request. The basic methodology is the same as those used in previous Department of Defense (DoD) Reports on National Defense Stockpile (NDS) Requirements.

Overview and Taxonomies of Demand

The overall objective of this portion of the analysis process is to compute shortfalls of materials. To do this, one must estimate the available supply of materials within the scenario time frame, and must also estimate the demand for them. Supply data are obtained more or less directly. But to compute demand for materials, a more indirect procedure is used. First, the analysis computes economy-wide demands for goods and services (i.e., demands on industry), and then the demands for materials are derived from the demands on industry.[1] In addition, portions of the process can consider demands for weapons in a military scenario. That is, the NDS modeling methodology considers three different broad categories of demand:

1. Demand for weapons in a military scenario, expressed in numbers of weapons or thousands of dollars (dollars are deflated to a constant year)
2. Demand for industrial output of goods and services, expressed in millions of dollars (deflated to a constant year)
3. Demand for materials, expressed in units (e.g., tons) of material. Dollar valuations of material amounts are computed for use on output reports

The models used in the analysis convert demand from the first category to the second, and then from the second category to the third. A supply or inventory in each category is also considered. All demands and supplies are time-phased streams, i.e., different demand and supply values are computed for each month or year of the scenario.

[1] This indirect method of computing material demand via first computing industrial demand facilitates accounting for demand across the whole U.S. economy.

Earlier demands cannot be offset by supplies that become available later. Supplies are not "perishable": earlier supplies can be used to offset later demands.

There is also a taxonomy of demand in terms of general economic sector: military, "industrial" or emergency investment,[2] and civilian. These sectors have formal definitions, as follows:

- *Military Sector*: The military sector includes military goods required during the emergency. This sector also includes a portion of the materials needed for replacement parts and equipment for existing government-owned industrial facilities, and new plant and equipment for government-owned facilities required in the manufacture of military goods if production occurred at normal (non-emergency) rates. The other two sectors include the additional new plant and equipment needed to produce at levels sufficient to meet emergency military demands.
- *Industrial Sector*: The industrial sector covers the construction of new plants and/or the manufacture of new equipment in the private sphere to overcome bottlenecks caused by accelerated production during a national security emergency. These bottlenecks are estimated by comparing defense-related and essential civilian requirements to the emergency operating capacity of existing plant and equipment. (In practice, this sector may be thought of most appropriately as the "emergency investment" sector.)
- *Essential Civilian Sector*: The essential civilian sector includes goods and services for general civilian use, excluding those considered nonessential for stockpile purposes. This sector includes a portion of the replacement parts and equipment for existing industrial facilities and new plant and equipment required in the manufacture of these goods if production occurred at normal (non-emergency) rates.

Military demand can be subdivided into ongoing (peacetime) military demand and "extraordinary" military demand associated with a conflict scenario. The models keep track of separate demand totals for each category.

General Outline of the Modeling Process

The analysis is based on the following framework:

1. A scenario for a military situation is specified. This scenario might involve a long mobilization period culminating in conflict; or, as in the 2013 Base Case

[2] The term "industrial demand" is often used to refer to demands for goods and services in general, i.e., the demand for output of industries. But at times, it is used to refer to emergency investment demand specifically. The meaning should be clear from the context.

(and all recent NDS Requirements studies) it might be a regeneration scenario, in which weapons and supplies lost in a conflict are rebuilt over a period of time. By suitably setting certain inputs, it is also possible to model some kind of ongoing, steady-state demand for weapons, or to model a peacetime case with no extraordinary total military demand.

2. This military situation gives rise to an extraordinary military demand for weapons, ammunition, and combat support material. Inventory (if it is appropriate to model it) is applied to reduce this demand.
3. The industrial outputs required to make these military items (net of inventory) are computed. As a result, the extraordinary military demand induces a demand on U.S. industry, possibly creating imbalances in the U.S. economy.
4. To the extraordinary military demand on industry, civilian and regular (base) military demands are added. The models then compare the industrial demand against supply. Supply includes net imports (i.e., imports minus exports). Shortfalls in industrial output, if any, are computed. The civilian demands, base military demands, imports, and exports can be multiplied by adjustment factors to reflect more accurately the situation being modeled. In particular, the civilian demands can be set to only include the portion of civilian demand deemed essential (see Appendix 14). Goods and services needed to repair homeland damage, while technically part of the extraordinary military demand, are usually included in the input files for base military and/or civilian demand.
5. If new plants and facilities are built, the additional output they produce can ameliorate some or all of the excess industrial demand. The analysis models this process. However, the goods and services required to build these plants and facilities become an additional source of demand. In the context of the study, this additional demand is referred to as the emergency investment demand. It refers only to the investment in plants and facilities necessary to address the extraordinary military demand. Spending for normal peacetime investment is included in the base military and civilian demand values.
6. The total demand on industry (extraordinary military plus base military plus civilian plus emergency investment, minus net imports) induces a demand for materials. This can be thought of as the materials required to produce or generate the goods and services.
7. Available material supplies, U.S. and foreign, are computed. Initial amounts of foreign supply might be subject to a number of different decrement factors, based on the particulars of the emergency scenario (see below). The available supply is the supply that the United States can use after all relevant decrement factors have been applied.

8. The demands for materials are compared with the available material supplies, in a time phased manner. Shortfalls are computed and noted.

The following sections provide some more explanation concerning certain portions of the above steps. As noted earlier, detailed descriptions of the modeling process can be provided upon request.

Economic Modeling for Computation of Demands for Goods and Services

The civilian industrial demands and base military industrial demands are computed by two long-range economic forecasting models developed by the Inter-industry Forecasting Project at the University of Maryland (INFORUM). The models are named LIFT (Long-term Inter-industry Forecasting Tool) and ILIAD (Inter-industry Large-scale Integrated and Dynamic Model). These models have the unique capability to link high-level measures of economic performance to demands for particular products and requirements for production by particular industries. The models are used to translate the Council of Economic Advisors' (CEA's) long-range economic forecast into output requirements for the specific industry sectors that buy and utilize materials.

LIFT is a macroeconomic model that includes an input-output matrix showing what 97 production sectors must buy from one another in order to make their products. LIFT forecasts gross domestic product (GDP) and its major components and then derives spending demands for 92 consumer products and services, 56 types of production equipment, 25 types of construction, and 25 types of defense spending. LIFT then calculates what each of the 97 production sectors must produce in order to satisfy the spending demands. The ILIAD model, which includes an input-output matrix for 360 production sectors, calculates output requirements for each sector. These results are projected in detail more than 10 years into the future.

The inputs to the two models are calibrated to match the CEA macroeconomic forecast and project the industry output requirements. Then, the results are modified to reflect DoD specifications regarding what civilian demands should be considered essential for stockpile purposes. The rich detail in these models enables DoD to discriminate among various types of demands in specifying what is essential. The input-output matrices in these models are also used to determine additional output requirements generated by the assumed military conflict.

From Demands for Goods and Services to Demands for Materials

For most of the materials studied, the material requirements are estimated using indices called material consumption ratios (MCRs), which are developed with the assistance of the Department of Commerce and the U.S. Geological Survey (USGS).

These ratios indicate the quantity of material (expressed in mass units, such as tons) that are consumed in the production of goods and services in each particular production sector, per billion dollars of economic output in that sector. That is, for each combination of material (72) and production sector (360), an MCR is computed. The MCR represents the amount of material needed for the given sector to produce a billion dollars (in constant-year dollars) worth of its output.

The dollar amounts of demands for goods and services computed via the economic modeling are multiplied by the MCRs to yield amounts of materials needed to satisfy these demands. Separate totals are kept track of for military, emergency investment, and civilian demands, for each material and year of the scenario. At this point, base military and extraordinary military demands are added together to yield a total defense demand amount.

Material Supply Modeling

After the material demands have been computed, the next stage is to compute the available material supply. The following procedure is performed separately for each material under consideration:

1. Start with projected peacetime material supply amounts (measured in mass units, such as tons), by country of origin (including the United States) and year of the scenario. The amount might correspond to capacity, estimated production, or something in between. Most of the data on supply amounts are furnished by the USGS.

2. Separate U.S. material supplies into current facilities, restart concerted programs and new/expansion concerted programs, and determine different U.S. supply levels. Appendix 3 provides more information on concerted programs, but they are assumed not to be available in the Base Case.

3. Determine each foreign country's supply use category. That is, can its supply be used to satisfy all categories of material demand (defense, emergency investment, and civilian) or to satisfy civilian demand only? The model allows several options for doing this.

4. For foreign supplies, apply decrement and delay factors to determine the amounts of available foreign supply, by year and country of origin. These factors model the effects of the underlying conflict scenario on material supply and include factors for supply shutoff from adversaries, war damage, shipping losses, infrastructure/ability degradation, anti-U.S. orientation, and foreign competition (market share). Appendix 3 discusses these factors in more detail and provides information on their values in the 2013 Base Case.

5. For each combination of use category and year, take the sum over country of the available foreign supply amounts to get a total available foreign supply for that use category and year. If useable foreign supply is to be capped at a multiple of current material imports, apply that cap.

Comparing Material Supply with Demand

After the available material supply has been determined, it is compared with material demand and the resulting shortfalls, if any, are computed. There are three categories of demand: defense (encompassing peacetime military plus extraordinary military), emergency investment, and civilian. There are also three categories of supply:

1. Domestic (U.S.) supply.
2. Foreign supply that can be used to offset demand in all categories (net amounts available after all decrement factors have been applied).
3. Foreign supply that can be used to offset civilian demand only (net amounts available after all decrement factors have been applied).

All supplies and demands are time-phased streams: separate supply and demand quantities are generated for each year of the scenario. The comparison algorithm is performed separately for each different material. It tries to maximize the amount of demand satisfied (and hence minimize the shortfall), subject to the following restrictions:

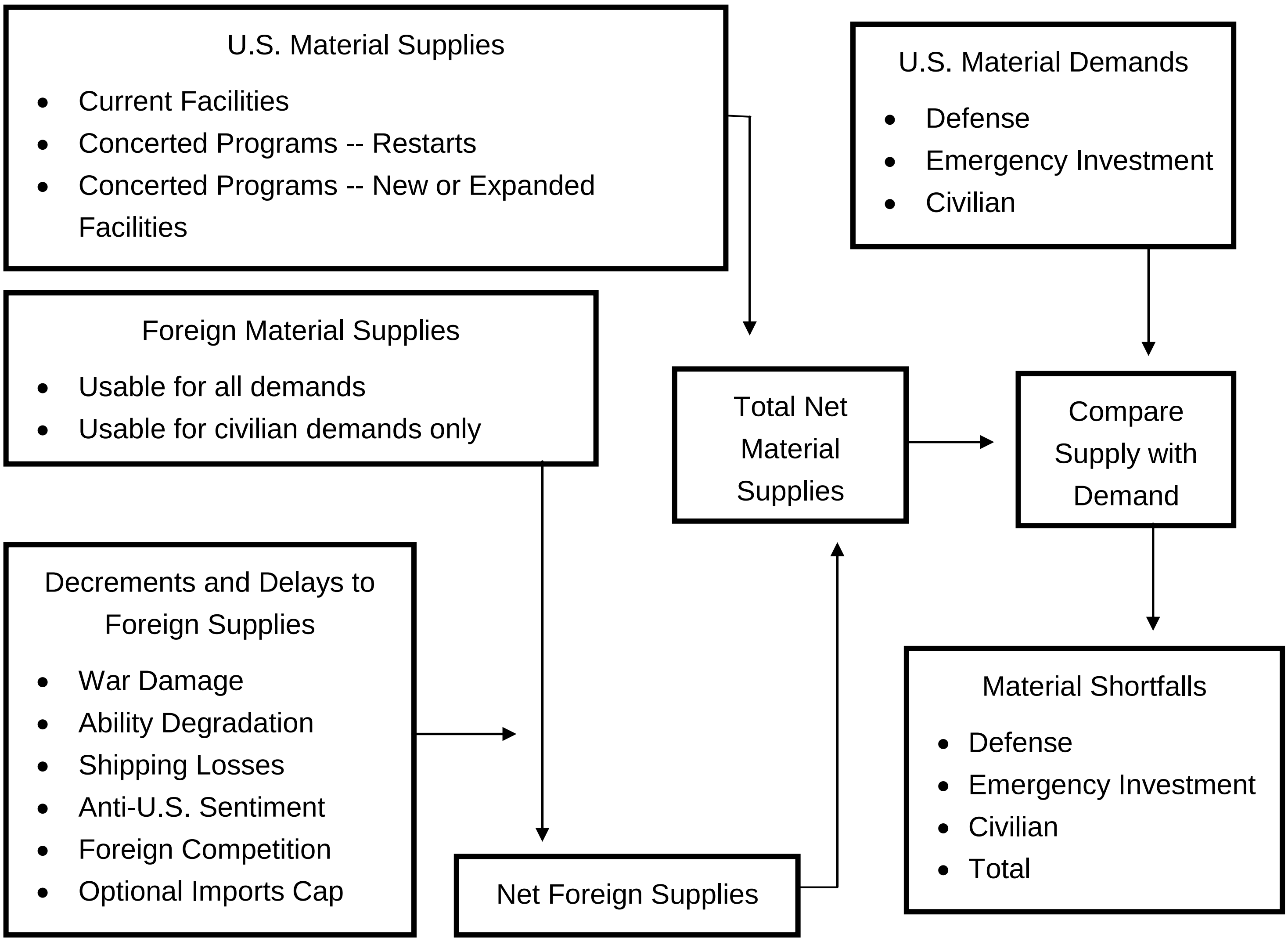
- Supply that becomes available in a certain year is not allowed to offset demand in earlier years.
- Foreign supply that can be used to offset civilian demand only cannot be used to satisfy defense and emergency investment demands.
- Attempt to satisfy defense demands first, then emergency investment, then civilian.
- Use U.S. supply in preference to foreign, where feasible.

Shortfalls, if any, as well as the available U.S. and foreign supply and the amount of foreign supply used are noted.

Summary Flowchart

The flowchart in Figure 7-1 illustrates the material supply modeling and demand/supply comparison process, putting together all of the elements described above.

Figure 7-1. Material Supply Modeling Methodology



Note: All quantities can vary by year.

Appendix 8
Inventory Methods and Approaches

Introduction

In its analyses supporting this report to Congress, DLA Strategic Materials has identified 23 materials with shortfalls in the NDS 2013 Base Case[1]. Two options for potentially preventing those shortfalls from becoming shortages in the event of the occurrence of the national emergency postulated in the Base Case are establishing inventories of those materials, either in the form of traditional government stockpiles or buffer stock inventories. This appendix describes those options and how they would serve to mitigate material shortfalls.

Government Stockpiles

The NDS is an inventory of strategic materials built and held to sustain U.S. defense and essential civilian demands in the event of a national emergency. The NDS is the United States' traditional means of mitigating the risk to the nation from cutoffs of material supplies from foreign sources. DLA Strategic Materials administers the NDS on behalf of the Stockpile Manager, Under Secretary of Defense (Acquisition, Technology, and Logistics). Executive or congressional authority is required to release materials from the NDS inventory. Rules governing release are defined in sections 5 and 7 of the Strategic and Critical Materials Stock Piling Act (50 United States Code (USC) § 98 et seq.). Section 5(b) requires congressional authorization for disposals from the NDS. Section 7 addresses executive authority to release materials from the NDS, and states:

> SECTION 7. (a) Materials in the stockpile may be released for use, sale or other disposition – (1) on the order of the Under Secretary of Defense for Acquisition, Technology, and Logistics, if the President has designated the Under Secretary to have authority to issue release orders under this subsection and, in the case of any such order, if the Under Secretary determines that the release of such materials is required for use, manufacture, or production for purposes of national defense; and (2) In time of war declared by the Congress or during a national emergency, on the order of any officer or employee of the United States designated by the President to have authority to issue disposal orders under this subsection,

[1] See Appendix 6 for shortfall amounts. The 23 materials comprise 22 for which the supply/demand comparison process found shortfalls, plus an extrinsically specified stockpile goal for beryllium metal.

> if such officer or employee determines that the release of such materials is required for purposes of national defense.
>
> (b) Any order issued under subsection (a) shall be promptly reported by the President, or by the officer or employee issuing such order, in writing, to the Committee on Armed Services of the Senate and the Committee on National Security of the House of Representatives.[2]

To acquire materials for the stockpile, the following steps are undertaken:

a. The action is submitted through the Stockpile Manager and Secretary of Defense to the Congress for legislative authority.

b. If legislative authority is approved, a request for funding is identified in the next program budget request cycle. Unless the legislative authority included a specific appropriation for the acquisition, the NDS Transaction Fund is the statutorily-mandated source of funds to be used for the acquisition.

c. Once legislative authority and funding are approved, the action is coordinated with Market Impact Committee to ensure the action does not disrupt normal markets.

Stockpile inventories of materials are funded from the NDS Transaction Fund (either from existing Principal Account funds or by specific appropriation to the Fund). Project scopes are developed by DLA Strategic Materials. Materials are acquired as direct acquisitions (or through other procurement arrangements) and are stored at government controlled facilities. Storage arrangements are based on the character of the material (e.g., is it hazardous or does it have a usable shelf life) and how it would be deployed in the event of a national emergency. Once a material is stockpiled, it is monitored at least semi-annually to assure the material is maintained in a form, condition, location and quantities that meet applicable requirements. Stockpiled material can be rotated periodically to keep material suitable for its intended uses. Rapid rotation may require administrative and legislative action.

Buffer Stock Inventories

An alternative approach to establishing and maintaining a government stockpile inventory of materials to mitigate shorter-term risks to the nation from cutoffs of relatively smaller quantities of material supplies is to establish buffer stock inventories. A buffer stock inventory is a progressive contingency contracting measure for increasing the U.S. government's ability to acquire materials to mitigate the risk from potential shortfalls. It involves the government qualifying and contracting with a vendor and requiring it to acquire and hold an extra inventory of a specified material that the

---

[2] 50 USC § 98f.

government might purchase if and when the need (e.g., a shortfall) arises. Buffer stock inventories guarantee that specified materials are both located in the United States and accessible to the government with specified quantities and lead times. The government in effect is financing an option (i.e., call) to acquire a material that may or may not be exercised. The annual cost to the government to maintain the buffer is estimated at 15 percent of the material acquisition cost (i.e., what the vendor paid for the material). At the time the government wishes to acquire the material, it then must pay the acquisition cost (see Appendix 12). As with NDS material acquisitions generally, buffer stock inventories are used when the supply of a material faces a substantial risk of interruption. They are intended to buffer (i.e., bridge) against a risk to supply until markets either correct themselves, new supplies are established, or demand for a material is reduced by substitutes. The government can ultimately obtain buffer stock inventory materials and establish a traditional government stockpile by exercising its right to purchase vendor-held inventories. Buffer inventories may be used instead of traditional government stockpiling if the government cannot or does not wish to acquire materials—either due to legislative constraints, market factors or budget limitations. Buffer inventories may be more quickly accessible for use than stockpile inventories because they are not subject to formal stockpile release requirements. However, should there be a subsequent need to acquire the materials for traditional government stockpiling purposes, legislative and other NDS requirements apply.

Buffer stock inventories also can be established with multiple suppliers and therefore help to develop and maintain a competitive, multi-source supply chain and avoid reliance on a single source of supply. Multiple suppliers can also later compete for subsequent material acquisitions that occur when the government demands material for delivery such as in the event of a future national emergency.

Appendix 9
Substitution

Introduction

Another possible option for mitigating shortfalls of materials during a national emergency is to use substitutes to meet demands for their applications. This appendix evaluates the extent to which substitute materials can be used to mitigate the shortfalls in the 2013 NDS Base Case. The general approach is to identify the most promising substitute materials for each of the strategic and critical materials' major application areas and then evaluate the utility and availability of the substitutes for each application area.

This appendix also estimates the cost of employing substitution for each material and specifies whether that cost would be incurred before the supply-disrupting scenario or during the scenario. It also addresses the extent to which that cost would have to be borne by the government as opposed to the private sector. The substitution results—the utility and availability of the substitutes and the costs—are used in the broader shortfall mitigation cost and risk assessment so that the cost-effectiveness of substitution can be compared to the cost-effectiveness of other shortfall mitigation options.

Approach

The first step in the approach for considering the potential for substitution to mitigate material shortfalls is to identify, for each of the shortfall materials, the most promising substitute materials by application area. The second step is to estimate and justify how much of the Base Case shortfall, material by material, can be mitigated through those substitutions that do not have any significant adverse performance effects or create other shortfalls. This step may further consider substitution possibilities that would create shortfalls but that would cost less than stockpiling the initial shortfall material (essentially exchanging a more expensive shortfall for a less expensive one). The last step in the approach is to estimate the relative costs—before the scenario (i.e., during peacetime, before the crisis) and during the scenario (conflict or crisis), and how much would be borne by the government—of various substitution options.

Research Protocol

To identify and evaluate candidate substitute materials for each of the Base Case shortfall materials, DLA Strategic Materials developed a protocol of research questions to be provided to subject matter experts to collect the information needed to do so. The protocol described below was provided to individual experts at the U.S. Geological Survey (USGS), the Institute for

Defense Analyses (IDA), and DLA Strategic Materials, which answered its questions for each shortfall material. Their answers were collated and then supplemented with further data gathered from additional experts, in government, industry, and academia, and the materials literature. The data were then synthesized to produce estimates of the extent to which substitution could mitigate the shortfalls for each of the shortfall materials in the Base Case Scenario.

The protocol's approach to the substitution assessment was to examine each strategic material individually. For each material, the expert was asked to consider each of its major areas of application and assess whether there are other materials that could, at least to some degree, substitute for the material in question in each area. It is the nature of the uses of materials (in most cases here, chemical elements) that one material can be a substitute for another material for some applications but not for others. It is also the case that substitutes may not be perfect. They may be suitable for only some of the uses of the strategic material in question within an application area. They may require the acquisition of additional capital or labor before being usable on a significant scale. They may also impose costs on product manufacturers or users such as production costs, operating costs, worker health and safety obligations, or environmental impacts. Nevertheless, the intent was to identify even partial or imperfect potential substitutes so that the DoD could determine the extent to which substitutes could be used to mitigate the effect of strategic material shortfalls. The sections below discuss each of the questions asked of the experts by the assessment protocol.

Identification of Potential Substitutes

The first step in the protocol was to identify candidate substitutes for each major application area of each of the Base Case shortfall materials. For each strategic material for which potential substitutes are to be identified, the experts were provided its major application areas in the United States. The application areas were taken from the database used to assess material demands for NDS analyses.[1] The experts were asked to identify each of the other materials that could serve as substitutes for the strategic material in each of its application areas. It was made clear to the experts that one material may be a suitable substitute for another material in one application area but not another. For those cases, the experts were asked to indicate the specific application areas of the strategic material in question for which the potential substitute material could be suitable.

For an example of a material being suitable as a substitute for a shortfall material in one application area but not another, tantalum's major application areas are: capacitors in personal electronics, superalloys in aircraft engines and parts, and medical and surgical equipment. Aluminum may be a suitable substitute for tantalum in capacitors but it is not a suitable

[1] The major application areas in the United States for each material and the fractions of the total U.S. demand of each material used in them are provided by the USGS as part of the NDS analytical process.

substitute for tantalum in superalloys or medical and surgical equipment. Molybdenum may be a substitute for tantalum in superalloys, but it is not a suitable substitute for tantalum in capacitors.

Finally, the experts were asked if there were any major areas of application for any of the Base Case shortfall materials that are important to evaluating the potential for the use of substitutes but which were not identified on the list of strategic materials and application areas provided. If so, they were asked to specify the application areas and evaluate the potential for substitutes to be used in those areas.

Assessment of the Extent to Which Each Substitute Can Be Used

The next step in the protocol was the determination of the extent to which each substitute candidate could be used for the shortfall material in question in each of its major application areas. The experts were asked, for each strategic material, each of its major application areas, and each candidate substitute material, what fraction of the strategic material used in each application area could the substitute replace.

The intent of this question was to capture the fact that while some material might be a suitable substitute for some strategic material used in one of its areas of application, it could be the case that the substitute is suitable for only some fraction of the uses or products within that area. This could be because of unique properties or particularly high performance required for certain specific applications within any given area of application. When answering this question, the experts were asked to keep in mind the high performance requirements that might be associated with defense applications in particular.

For an example of a substitute that might be suitable for only a portion of the uses within an application area for a shortfall material, one of antimony's major application areas is in flame retardants in clothing and other products. Substitutes for antimony in that area include boron and other compounds; but because of the performance requirements in that application area, the substitutes were found to be suitable for only about 50 percent of the applications for antimony. This question was asked for each strategic material, each of its application areas, and each of its potential substitutes.

Time Frame in Which Each Substitute Can Be Used

The next question in the protocol was how quickly the substitute could be brought into use to a significant extent. For each strategic material, each of its major application areas, and each candidate substitute material, the experts were asked how soon, in the event of a crisis or supply disruption, the substitute would be used. They were asked specifically whether each substitute could be used immediately, in the short term (i.e., one to six months), in the medium term (i.e., six months to two years), or in the long term (i.e., longer than two years).

The intent of this question was to determine how soon, in the event of a sudden and possibly unexpected crisis and in light of everything that would need to be done to facilitate it, substitutes for the strategic material could replace that material in each of its application areas. A longer time horizon can allow greater use of substitutes as new products are designed potentially to avoid materials in short supply. But the shorter time horizon available to respond to a crisis can pose a barrier because of the lack of product designs, production facilities, and other necessary enabling capabilities.

For example, if it would take over two years to modify and certify product designs and establish the production capacity necessary to use composites in place of beryllium metal in commercial structural applications, then the answer to this question with respect to the substitution of composites for beryllium in that application area would be “in the long term.”

It happens to be the case in the Base Case Scenario that almost all of the shortfalls occur only in the first year of the scenario. Thus, as shown later when discussing results, the only substitutes that would be useful in the Base Case are those that would be available in the short term.

The Nature of the Substitution to Be Made

The next question in the protocol concerned the nature of the substitute and its application. For each strategic material, each of its major application areas, and each candidate substitute material, the experts were asked to explain whether the substitute would replace the strategic material on a one-for-one basis or would it replace the strategic material in similar but not identical products.

Some substitutes, like alloying agents, can be used in identical products on a one-for-one or nearly one-for-one basis. Others require the product design to be modified somewhat so that the new product is similar but not identical to the one using the strategic material being replaced. Still others are used in products that perform the same function as products using the shortfall material but via a different approach. For example, different types of stainless steel may substitute for each other in pressure vessels on nearly a one-for-one basis. The resulting vessels are nearly identical to each other although their performance or cost may differ somewhat. For another example, if tin-plated steel is used instead of aluminum to make cans, the cans perform the same function as before but their design and construction, because of the nature of the substitute materials, must be somewhat different.

The Amount of the Substitute Material Required and Other Impacts on Materials Usage

The next question in the protocol is what quantity of substitute materials is required to replace the shortfall material. For each strategic material, each of its major application areas, and each candidate substitute material, the experts were asked how much of the substitute material would have to be used to replace each unit mass (e.g., tr.oz., kg, ton) of the strategic material in that application. For each of those instances, they were asked whether the change from the strategic material to the substitute requires changes to the use of other materials in the production process for the products containing the substitute.

In considering the substitution of other materials for strategic materials that might experience shortfalls under certain conditions, we need to ascertain how much of the substitute materials would be required so that we can assess whether any of the substitutes might also experience shortfalls. We also need to know whether changing to substitutes could change the consumption pattern for other materials used in the production of the products containing the substitute (like solvents or materials that would come into contact with the substitute) sufficiently to significantly affect the consumption of strategic and critical materials in the United States.

For example, if aluminum were substituted for copper in electrical wiring, 485 kg of aluminum would be required for each 1,000 kg of copper replaced. Using aluminum instead of copper would also require the use of the materials consumed in the smelting of aluminum in lieu of the materials used in the smelting of copper.

Key Enablers Needed to Facilitate Substitution

The next question in the protocol concerned supply and production-related capabilities needed to enable the use of the substitutes. The experts were asked, for each strategic material, each of its major application areas, and each candidate substitute material that could substitute for the strategic material in each of its applications, what would be required to enable that substitution to take place.

In some cases, one material may be substituted for another immediately, without anything new required in the supply chain that would produce the products containing the substitute. In other cases, however, certain key enablers are needed before the substitution can take place. For example, there may be a need for new product designs or, in the case of regulated industries (like defense), government design certifications. Certain customers may have requirements that specify the use of particular materials in products. There may be a need for new or modified production facilities or an expansion of capacity at existing facilities. There may be a need for more labor or possibly retrained labor to operate the supply chain. There may be a need for new networks of material suppliers to provide material feed stocks, including the substitute material. There may be legal limits that restrict the use of certain substitutes. This question is aimed to capture those items to ascertain what was necessary, beyond a supply of substitute materials or products, to enable the substitutes to be used.

Additional Costs Incurred in Using the Substitutes

Similar to the last question, this question in the protocol asked about additional costs or consequences involved in the use of substitutes for shortfall materials. The experts were asked, for each strategic material, each of its major application areas, and each candidate substitute material that could substitute for the strategic material in each of its applications, what additional costs or burdens might be incurred if the substitute were used.

Materials tend to be used where the market determines that their application is optimal (relative to other material choices) with respect to performance (considered broadly) and cost. Thus, substituting one material for another in some application typically imposes one or more burdens in the life cycle of the product, even if only to shift the balance between cost and performance. Potential such burdens can include: production costs, product operating and maintenance costs, product lifespan limitations, waste disposal or recycling costs, environmental impacts, energy usage, health and safety obligations, risks arising from foreign supply chains, and the cost or burden of switching back to the original material after the supply disruption is over. This question asked for the identification of each such burden that would be imposed if a substitute replaced the strategic material in question in each of its areas of application.

Final Evaluation of Overall Substitutability

The last question in the protocol asked about the overall attractiveness of using each of the candidate substitute materials in each of the shortfall material application areas for which the substitutes were being considered. The experts were asked, given all that they understand regarding the costs and benefits of potentially replacing strategic materials with their substitutes—for each strategic material, each of its major application areas, and each candidate substitute material that could substitute for the strategic material in each of its applications—how attractive would the substitution be on a linear 1–10 scale (with a 1 being a highly unattractive, just barely usable substitute, and a 10 being a nearly perfect, minimal-burden substitute).

The intent of the overall rating was to allow other analysts and modelers, and potentially policy-makers and their staffs, to quickly get a sense of the extent to which material substitution could mitigate the risk of a shortfall of one or more strategic materials in their various applications. It was understood, however, that final decisions on whether to rely on substitution to mitigate risk as a matter of policy would likely turn on consideration of all of the available information concerning the costs and benefits and potential further risks related to doing so.

Sources of Data

As noted above, to collect the data needed to perform the substitution assessment, the protocol of research questions just discussed was developed and provided to individual experts at USGS, IDA, and DLA Strategic Materials. Their answers were collated and then supplemented with further data gathered from additional experts, in government, industry, and academia, and the materials literature. Those data were synthesized to estimate the extent to which substitution could mitigate the shortfalls for the Base Case Scenario shortfall materials.

The following organizations were consulted in collecting data for the substitution assessment:

Table 9-1. Organizations Consulted in Conducting Substitution Assessment

USGS
DLA Strategic Materials
IDA
Department of Defense (Air Force Materiel Command/Air Force Research Lab)
Department of Defense (Army Research Lab)
Department of Energy (Headquarters)
Department of Energy (Ames Laboratory)
Department of Commerce
Central Intelligence Agency
Office of Science and Technology Policy
National Academy of Sciences (Committee on Critical Mineral Impacts on the U.S. Economy, Committee on Earth Resources, Board on Earth Sciences and Resources)
Massachusetts Institute of Technology
GE Global Research
Molycorp, Inc.
Arnold Magnetic Technologies Corp.
Electron Energy Corp.
Rare Earth Industry and Technology Association
The Boeing Company
Pratt & Whitney
The Rhodia Group

The table below indicates the sources of data for the substitution assessments for the Base Case shortfall materials on a material by material basis:

Table 9-2. Sources of Data for Substitution Assessment

Material	**Data Sources**
Aluminum Oxide, Fused Crude	Don Olson, USGS; see also U.S. Geological Survey, *Mineral Commodity Summaries 2010* (2010)
Antimony	James Carlin, USGS
Beryllium Metal	Brian Jaskula, USGS; Janet Sater, IDA
Bismuth	James Carlin, USGS
Chromium Metal	John Papp, USGS; U.S. Geological Survey, *Mineral Commodity Summaries*, 2012
Dysprosium	Dan Cordier, USGS; Alex King, Ames Laboratory, DOE; Bill McCallum, Ames Laboratory, DOE; Iver Anderson, Ames Laboratory, DOE; Karl Gschneidner, Ames Laboratory, DOE; Doris Schuler et al., *Study on Rare Earths and Their Recycling, Final Report for The Greens/EFA Group in the European Parliament*, Öko-Institut e.V., January 2011, pp. 98-99.; Adam Aston, "China's Rare Earth Monopoly," *Technology Review*, October 15, 2010
Erbium	James B. Hedrick, Hedrick Consultants; U.S. Geological Survey, *Mineral Commodity Summaries*, 2012; Daniel J. Cordier, PG, Exploration Manager, Molycorp; Jones, E.D., Lawrence Livermore National Laboratory, *Outcomes of U.S.-Japan Roundtable on Rare Earth Elements R&D for Clean Energy Technologies*, Dec 3, 2010; Joe Gambogi, USGS; Karl Gschneidner, Ames Laboratory, DOE; Marko Slusarczuk, IDA
Fluorspar, Acid Grade	Mike Miller, USGS
Gallium	Brian Jaskula, USGS; Nayanee Gupta, IDA
Germanium	Dave Guberman, USGS; Nayanee Gupta, IDA
Manganese Metal, Electrolytic	Lisa Corathers, USGS; Justin Scott, IDA
Scandium	Michael Rigdon, IDA; James B. Hedrick, Hedrick Consultants; U.S. Geological Survey, *Mineral Commodity Summaries*, 2012; Daniel J. Cordier, PG, Exploration Manager, Molycorp; Joe Gambogi, USGS; Karl Gschneidner, Ames Laboratory, DOE; Thijssen, J. LLC, *Market Impacts of Rare Earth Element Use in Solid Oxide Fuel Cells*, prepared for National Energy Technology Laboratory, Oct 18, 2010; Thijssen, J. LLC, *Solid Oxide Fuel Cells and Critical Materials: A Review of Implications*, prepared for National Energy Technology Laboratory, May 10, 2011
Silicon Carbide	Don Olson, USGS; Bill Hong, IDA; Michael Rigdon, IDA
Tantalum	John Papp, USGS; Justin Scott, IDA

Table 9.2. Sources of Data for Substitution Assessment (Concluded)

Material	Data Sources
Terbium	Dan Cordier, USGS; Alex King, Ames Laboratory, DOE; Bill McCallum, Ames Laboratory, DOE; Iver Anderson, Ames Laboratory, DOE; Karl Gschneidner, Ames Laboratory, DOE; Doris Schuler et al., *Study on Rare Earths and Their Recycling, Final Report for The Greens/EFA Group in the European Parliament*, Öko-Institut e.V., January 2011, pp. 98-99.; Adam Aston, "China's Rare Earth Monopoly," *Technology Review*, October 15, 2010; Steven Duclos, Chief Scientist and Manager, Material Sustainability, GE Global Research, Testimony Before the Subcommittee on Investigations and Oversight of the House Committee on Science and Technology, February 10, 2010, pp. 7-8; Schuler et al., *Study on Rare Earths and Their Recycling,* p. 103; DOE, *Critical Materials Strategy*, p. 22-24; Diana Bauer, DOE.
Thulium	James B. Hedrick, Hedrick Consultants; U.S. Geological Survey, *Mineral Commodity Summaries*, 2012; Daniel J. Cordier, PG, Exploration Manager, Molycorp; Joe Gambogi, USGS; Karl Gschneidner, Ames Laboratory, DOE; Marko Slusarczuk, IDA
Tin	James Carlin, USGS
Tungsten	Kim Shedd, USGS; Nayanee Gupta, IDA
Yttrium	Dan Cordier, USGS; Steven Duclos, Chief Scientist and Manager, Material Sustainability, GE Global Research, Testimony Before the Subcommittee on Investigations and Oversight of the House Committee on Science and Technology, February 10, 2010, pp. 7-8; Schuler et al., *Study on Rare Earths and Their Recycling,* p. 103; DOE, *Critical Materials Strategy*, p. 22-24; Diana Bauer, DOE.

Evidence/Data Regarding the Utility of Substitutes for Mitigating Shortfalls

For each shortfall material and each of their major application areas, the responses to the research protocol were collated to identify the substitute materials, the fraction of U.S. demand for the shortfall material for that application that the substitutes could collectively meet, the additional enabling capabilities, if any, that would be required to use the substitutes, and the other costs and consequences, if any, of using the substitutes. Where the information provided by the experts in their answers to the protocol was not sufficient to answer those questions, it was supplemented with further information collected from the responding experts, additional experts, or the literature. The table below provides collated data for each of the Base Case shortfall materials and their application areas. Application areas with substitutes that are useable immediately or nearly so are highlighted in dark gray. Areas with substitutes usable only after significant delay (six months or more) are in light gray. Those substitutes in light gray are not usable to mitigate shortfalls in the Base Case Scenario. Application areas with no substitutes identified are in white. Substitution possibilities that themselves showed shortfalls are not considered as mitigation options in this analysis.

Table 9-3. Evidence/Data Regarding the Utility of Substitutes for Mitigating Shortfalls

Material	Application	Substitutes	Fraction of U.S. Demand (percent)	Application Fraction Substituted (percent)	Total Fraction Substituted (percent)	Enabling Capabilities Required	Costs/ Consequences
Aluminum Oxide, Fused Crude	Abrasive products	Emery, aluminum-zirconium oxide, metallic abrasives, boron carbide	89	100	89	None	Significantly higher (2-3x) material costs
	Clay building material, refractory manufacture		6	0			
Antimony	Plastics and resins (flame retardants)	Boron and other compounds	36	50	19	None	Higher material costs
	Storage batteries		16	0			
	Ammunition	Manganese, copper	11	5		None	Higher material costs
	Adhesives		5	0			

Table 9-3. Evidence/Data Regarding the Utility of Substitutes for Mitigating Shortfalls (continued)

Material	Application	Substitutes	Fraction of U.S. Demand (percent)	Application Fraction Substituted (percent)	Total Fraction Substituted (percent)	Enabling Capabilities Required	Costs/ Consequences
Beryllium Metal	Defense and aerospace applications	Graphite-fiber, carbon-fiber reinforced polymer, or fiber metal matrix composites	50	50	37	Product designs and certifications, production facilities, specialized labor	Product lifespan impacts, potential reliance on foreign supplier of fiber, production costs
	Nuclear applications		25	0			
	Commercial applications	Graphite-fiber, carbon-fiber reinforced polymer, or fiber metal matrix composites	25	50		Product designs and certifications, production facilities, specialized labor	Product lifespan impacts, potential reliance on foreign supplier of fiber, production costs
Bismuth	Primary aluminum production		10	0	2		
	Primary ferrous metal products	Lead	11	5		None	Few if any—choices at the margin
	Pharmaceuticals and medicines	Magnesium compounds	30	5		None	Few if any—choices at the margin
	Toiletries		6	0			
	Soaps and cleaners		5	0			

Table 9-3. Evidence/Data Regarding the Utility of Substitutes for Mitigating Shortfalls (continued)

Material	Application	Substitutes	Fraction of U.S. Demand (percent)	Application Fraction Substituted (percent)	Total Fraction Substituted (percent)	Enabling Capabilities Required	Costs/ Consequences
Chromium[a]	Aerospace applications	Other alloys (e.g., titanium)	75	0	13	Product redesign and recertification	Performance (fuel consumption)
	Metal containers, packaging, shipping materials	Other alloys (e.g., titanium)	10	90		None	Some weight gain or reduced performance
	Other: Motor vehicle parts, welding, electrical equipment	Other alloys (e.g., titanium)	8	50		None	Some weight gain or reduced performance
Dysprosium	Phosphors		17	0	8		
	Permanent magnets	Electromagnets	80	10		None	Higher system operating costs

Table 9-3. Evidence/Data Regarding the Utility of Substitutes for Mitigating Shortfalls (continued)

Material	Application	Substitutes	Fraction of U.S. Demand (percent)	Application Fraction Substituted (percent)	Total Fraction Substituted (percent)	Enabling Capabilities Required	Costs/ Consequences
Erbium	Fiber Optic Cables		55	0	16		
	Alloys	Other rare earths	15	90		Substitute alloys	Need to use rare earths not in short supply
	Chemical industry	Glass colorants	13	0			
	Lasers	Non-laser skin treatments	5	50		None	Some loss of capability
Fluorspar, Acid Grade	Hydrofluoric acid production	Imported hydrofluoric acid	90	100	100	None	Potential health, safety, or environmental costs, reliance on imports
	Primary aluminum production	Imported aluminum fluoride, cryolite, and crushed tapped bath	10	100		None	Potential health, safety, or environmental costs, reliance on imports
Gallium	Integrated circuits	Silicon	67	20	23	Product designs and certifications, production processes	Production costs
	Optoelectronic devices	Silicon, cadmium telluride, indium phosphide	31	30		Product designs and certifications	None

Table 9-3. Evidence/Data Regarding the Utility of Substitutes for Mitigating Shortfalls (continued)

Material	Application	Substitutes	Fraction of U.S. Demand (percent)	Application Fraction Substituted (percent)	Total Fraction Substituted (percent)	Enabling Capabilities Required	Costs/ Consequences
Germanium[b]	Fiber-optic systems	Fluorine, plastic optical fiber	50	0	15	Product design, infrastructure design, production facilities, material suppliers	Production costs, waste disposal, recycling, environmental and safety impacts of fluorine
	Infra-red optics	Chalcogenide glasses, zinc selenide	30	50		Product designs, production facilities, material supplier networks, specialized knowledge	Zinc Selenide health hazard
	Electronics and solar applications	Silicon	15	0		Product designs	Potential increase in operating costs
	Phosphors, metallurgy, and chemotherapy	Naturally fluorescing materials such as willimite, halophosphate phosphors; traditional chemotherapy drug treatments	5	0		None	Few if any

Table 9-3. Evidence/Data Regarding the Utility of Substitutes for Mitigating Shortfalls (continued)

Material	Application	Substitutes	Fraction of U.S. Demand (percent)	Application Fraction Substituted (percent)	Total Fraction Substituted (percent)	Enabling Capabilities Required	Costs/ Consequences
Manganese Metal, Electrolytic	Metal cans/boxes/other containers		62	0	0		
	Welding and soldering equipment		12	0			
Scandium	Sporting goods	Aluminum, titanium, carbon fiber, steel, wood	70	100	80	None	Some lower performance
	Metallurgical research		3	0			
	High intensity metal halide lamps	Alternative lighting products	20	50		None	Less desirable, some loss of performance
	Analytical standards		3	0			
	Aerospace alloys		4	0			
Silicon Carbide	Abrasive products	High purity aluminum oxide, abrasive diamond	59	25	25	None	Possible contamination tolerance issues with aluminum oxide
	Motor vehicle parts	Organic/metal composites, cast iron	10	100		None	Higher operating costs and life span impacts

Table 9-3. Evidence/Data Regarding the Utility of Substitutes for Mitigating Shortfalls (continued)

Material	Application	Substitutes	Fraction of U.S. Demand (percent)	Application Fraction Substituted (percent)	Total Fraction Substituted (percent)	Enabling Capabilities Required	Costs/ Consequences
Tantalum	Electronic components	Aluminum	58	90	52	New product designs and design certification needed; new manufacturing production facilities required	None
	Aircraft engines and engine parts		25	0			
	Surgical and medical instruments		6	0			
	Surgical appliances and supplies		5	0			
Terbium	NdFeB magnets	Electromagnets	50	10	21	None	Higher system operating costs
	Dopant for solid state devices		5	0			
	Alloys for actuator, sensor, magnetochem devices		3	0			
	Phosphors (fluorescent)	Incandescent and older fluorescent lights, light–emitting diodes (LEDs)	33	50			Some higher acquisition and operating costs, energy usage, relaxation of energy regulations on the use of older lighting technologies
	Phosphors (display screens)		7	0			
	Lasers		3	0			

Table 9-3. Evidence/Data Regarding the Utility of Substitutes for Mitigating Shortfalls (continued)

Material	Application	Substitutes	Fraction of U.S. Demand (percent)	Application Fraction Substituted (percent)	Total Fraction Substituted (percent)	Enabling Capabilities Required	Costs/ Consequences
Thulium	Lasers	Other lasers, non-laser surgical means	20	25	50	None	Some loss of performance
	Ceramics	Alternative colorants	20	75		None	Less desirable
	X-ray source	Alternative x-ray sources	10	50		None	Some loss of performance and portability
	Other uses	Alternative lighting means	50	50		None	Little loss of performance
Tin	Electronic components		37	0	6		
	Metal cans, boxes, containers	Epoxies, aluminum, chromium	17	35		None	Moderately higher costs, toxicity of chromium (valence 6)
	Architecture, structural metal products		6	0			
	Chemicals	Lead	11	5		None	Few if any—choices at the margin

Table 9-3. Evidence/Data Regarding the Utility of Substitutes for Mitigating Shortfalls (continued)

Material	Application	Substitutes	Fraction of U.S. Demand (percent)	Application Fraction Substituted (percent)	Total Fraction Substituted (percent)	Enabling Capabilities Required	Costs/ Consequences
Tungsten[c]	Steels (FeW)	Molybdenum	4	0	8	Production (heat treatment) facilities	Some performance loss
	Cemented carbide	Tool steels, stainless steels, ceramics, cements, boron nitride	50	0		Product designs, design certification, production facilities	Product lifespan impacts, limited performance
	Alloys	Nickel and molybdenum alloys	15	0		New production processes and product designs	
	Mill products	Lead, depleted uranium, molybdenum	16	53		Relaxation of regulations against lead usage, handling of radioactive material	Environmental and health
	Other misc. apps		15	0			

Table 9-3. Evidence/Data Regarding the Utility of Substitutes for Mitigating Shortfalls (concluded)

Material	Application	Substitutes	Fraction of U.S. Demand (percent)	Application Fraction Substituted (percent)	Total Fraction Substituted (percent)	Enabling Capabilities Required	Costs/ Consequences
Yttrium	Trichromatic fluorescent lights	Incandescent and older fluorescent lights, LEDs	39	50	19	None	Some higher acquisition and operating costs, energy usage, relaxation of energy regulations on the use of older lighting technologies
	Phosphors for color televisions and computer monitors		16	0			
	Stabilizer for zirconia and other ceramic materials		14	0			
	Fuel additives		6	0			
	X-ray intensifying screens		5	0			

a. Chromium substitutes are alternative alloys or functional substitutes, not direct material substitutes. Substitutes available with delay as follows: aerospace applications (75 percent).

b. Substitutes available with delay as follows: fiber-optic systems (100 percent), electronics and solar applications (25 percent), phosphors, metallurgy, and chemotherapy (100 percent).

c. Substitutes available with delay as follows: steels (90 percent), cemented carbides (70 percent), alloys (90 percent), mill products (73 percent).

Results and Observations

From the data above, one can make observations about the utility of substitutes in mitigating shortfalls in the Base Case scenario and the potential cost savings, over stockpiling, that reliance on substitutes could allow DoD to achieve. One also can make some general observations about the likely utility of substitutes for mitigating shortfalls in other material supply disruption scenarios.

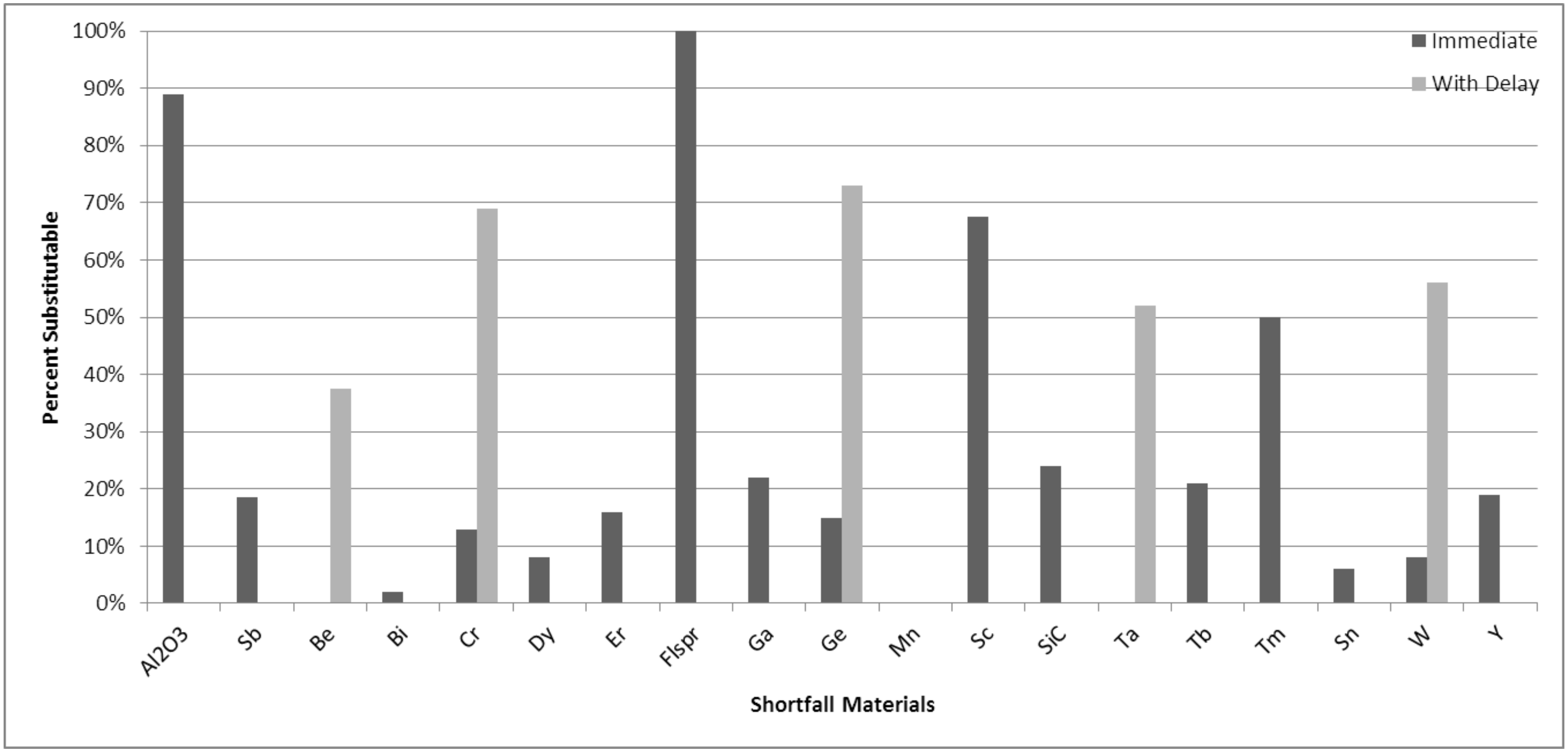
Results

Figure 9-1 below shows the fraction of total U.S. civilian demand for each shortfall material in the Base Case that could be met, collectively, by substitutes. The dark gray bars indicate materials for which substitutes could be used very soon—immediately or within a few months of the beginning of a crisis or conflict. The light gray bars indicate materials for which substitutes could only be used with some delay—from six months to two years or more after the beginning of a crisis or conflict. Two materials, germanium and tungsten, each with a dark gray or light gray bar, are slightly substitutable immediately but much more so with delay. Because nearly all of the Base Case material shortfalls occur only in the first year of the scenario, the use of the substitutes available only with delay would not help to mitigate those shortfalls. Beryllium, whose symbol is underlined, has a military shortfall.

Figure 9-1 shows a broad range of results. Some shortfall materials, like aluminum oxide and acid-grade fluorspar, are highly amenable to the use of substitutes—nearly all of their demand could be met with substitutes with little or no delay. Most materials, like antimony and erbium, are partly amenable to the use of substitutes. Some materials, like beryllium and tantalum, are partly amenable to the use of substitutes, but they can only be used with delay. One material, manganese metal, is not amenable to the use of substitutes at all, even with delay.

It should be noted that these results reflect the usable substitutes that have been identified by research to date. Upon continuing this research, one might discover additional substitutes for the shortfall materials in their various applications. That would increase the fractions of total demand that could be met by substitutes that are shown in the figure.

Figure 9-1. Substitutability of Base Case Shortfall Materials



Given the extent to which demand for the shortfall materials could be satisfied through the use of substitutes, the next step is to ascertain how much of the Base Case shortfall for each material could be eliminated through the use of substitutes. Figure 9-2 shows the amounts of the Base Case shortfalls, in millions of dollars' worth of material (for each material), that could be mitigated by using substitutes, and are indicated by the light gray bars. Those amounts were calculated, for each material, by determining the year by year supply available in the form of substitutes and subtracting that from the shortfall amounts. Material costs are based on the material prices used elsewhere in this report. The dark gray bars in the figure indicate the amounts of the shortfalls that would remain after substitution was used to mitigate the original shortfalls (which are indicated by the total height of the light gray and dark gray bars).

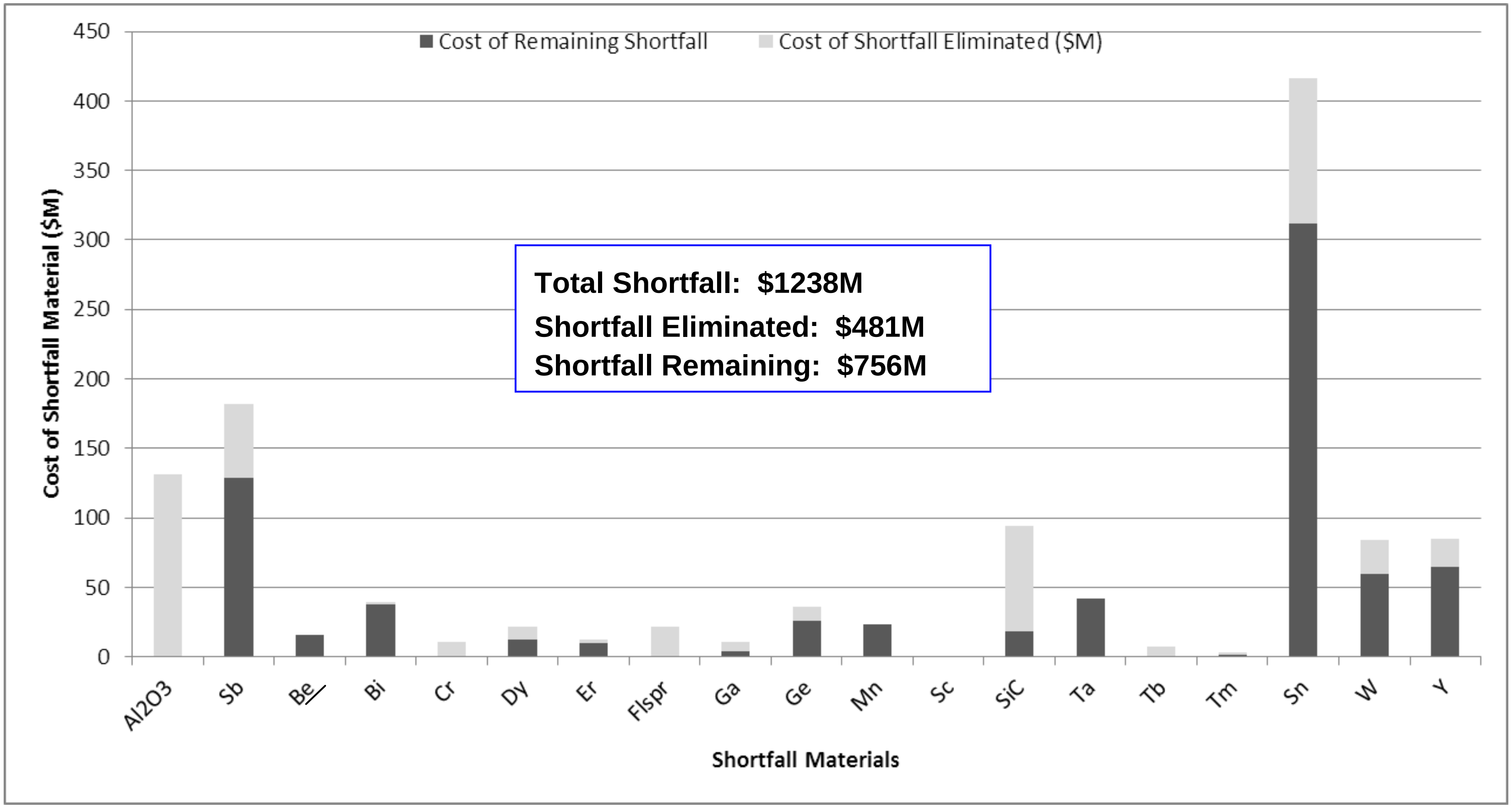
For the purpose of this analysis, it was conservatively assumed that substitutes could not be used to meet military demand for a material.[2] That is because military systems tend to be complex and military applications tend to be more demanding in terms of performance. For some systems, no alternative to the material used in the design is suitable. For many other systems, the design certification process is so onerous and time consuming that the substitute material, even if theoretically acceptable in terms of performance, could not be brought into use in time to mitigate a shortfall during the scenario in question. This assumption is reflected in the shortfall elimination results in Figure 9-2.

Figure 9-2 also shows a broad range of results. Some shortfalls, like those for aluminum oxide and acid-grade fluorspar, could be completely eliminated by the use of substitutes. Some other shortfalls, like those for silicon carbide, could be mostly eliminated by the use of substitutes. Some, like those for antimony, bismuth, and dysprosium, could be only partly eliminated. And some, like those for manganese and tantalum, cannot be reduced at all. In sum, it is estimated that of the total Base Case civilian shortfall of $1.2 billion worth of materials, $481 million, or about 39 percent, could be eliminated by the use of substitution.

---

[2] Where military applications are similar to substitutable civilian applications this assumption is overly restrictive. But it provides a conservative bound on the extent to which substitution could be relied upon to eliminate shortfalls for NDS planning purposes. Because defense shortfalls tend to be small compared to civilian shortfalls, it has a small effect on the final results of the analysis.

Figure 9-2. Extent to Which 2013 NDS Base Case Shortfalls Can Be Mitigated Through Substitution



Observations

Some general observations can be made from these results that would likely apply in a broad range of material supply disruption scenarios. First, substitutes are potentially available for most of the Base Case shortfall materials. The fractions of demand that they could meet ranged from zero to nearly 100 percent. In sum, substitutes appear sufficient to mitigate a significant fraction of the total Base Case shortfall. Based on discussions with experts and a review of the literature, substitutes will be usable, at least to some extent, for most of any materials found to be in shortfall in a supply disruption scenario. Some substitutes would be available only after some delay (maybe six months to two years or more) to allow enabling capabilities (e.g., product designs and certifications, supplier networks) to be put into place. They may not be useful in scenarios with early shortfalls like the 2013 NDS Base Case.

Second, some substitutes work indirectly, at the functional or system level, rather than directly. When evaluating additional shortfall materials for substitution possibilities, indirect or functional substitution should be considered if direct substitution cannot mitigate much or any of the shortfalls.

Third, substitutes tend to be available more so for civilian applications than for military applications. That is because military systems tend to be complex and military applications tend to be more demanding in terms of performance. For some systems, no alternative to the material used in the design is suitable. For many other systems, the design certification process is so onerous and time consuming that the substitute material, even if theoretically acceptable in terms of performance, could not be brought into use in time to mitigate a shortfall during the scenario in question.[3] Nevertheless, because, as a general rule, military demand is satisfied before civilian demand, substitutes may be able to eliminate all of a shortfall for a material with military applications—just so long as the shortfall is not large enough to cause military demand to go unmet (i.e., to create a defense shortfall).

Fourth, for some materials for which substitutes can only meet a modest fraction of total demand (e.g., silicon carbide), they can still eliminate a relatively large fraction of the material's shortfall. This is because for some materials, the shortfall represents only a fraction rather than all of the U.S. demand for the material.

3 As noted, there are exceptions to this—some defense-related products are similar to their civilian counterparts and hence would be amenable to having demand for them met through the use of substitutes.

Substitution Cost Assessments

The NDS substitution assessment also evaluated the relative cost of using substitution to mitigate material shortfalls. The ultimate goal of the reconfigured NDS is to be able to manage material supply-related risk in the most cost effective way. Part of that requires knowing the relative costs of the measures that might be available to mitigate various potential material shortfalls. It turns out that with substitution the government has broad latitude as to which costs it will incur and which it will allow to be incurred by the private sector (in part because the demand being met is entirely civilian demand). Thus, the question of the cost effectiveness of substitution compared to other mitigation measures may be in part—perhaps in large part—a matter of political judgment.

There are several potential costs that either the government or the private sector might incur in using substitutes. First, there is the cost of the substitute materials (or substitute products, in the case of functional substitutes) relative to the cost of the shortfall material. Second, there are the direct costs associated with the additional enabling capabilities needed to use the substitute on a significant scale. These include product designs, design certifications, production facilities, specialized labor, and material supplier networks. Third, there are indirect costs or consequences (or possibly savings or benefits) that might be associated with the use of substitutes.[4] These can include production costs for products that contain the substitutes, increased (or possibly decreased) product operating and maintenance costs, product lifespan impacts (positive or negative), health/safety/environmental impacts, energy usage impacts, and waste disposal/recycling issues.

In the 2013 NDS Base Case, as shown in the data section above (Table 9-3), some of the substitutes that would be usable to mitigate material shortfalls could have material costs higher than the shortfall material they would be replacing. It is difficult to estimate material costs during a conflict or crisis because shortages drive up market prices; but as shown in the data section, the current prices of some of the substitutes considered here are higher (and in a few cases significantly higher) than the current prices of the shortfall materials. Beyond the material costs, the use of these substitutes would not impose any significant costs for enabling capabilities because none are needed.

Because the substitutes must be available quickly to be usable to mitigate 2013 NDS Base Case shortfalls, these substitutes are almost entirely materials or products already in use in the marketplace. Thus, enabling capabilities like production facilities and skilled labor are largely already in place for them. As indicated in the data section above, the

[4] In some cases, the substitute may be a more expensive but higher performing material than the shortfall material. In those cases, there may be ancillary benefits (as opposed to consequences) associated with using the substitute.

use of substitutes could impose several kinds of ancillary consequences like product operating costs, reduced product life spans, and environmental costs. Indirect costs have not been further specified.

In addition to the particular costs or consequences associated with the use of substitutes, two important questions are when those costs or consequences would be incurred and by whom. First, regarding the timing of potential costs, for the 2013 NDS Base Case shortfall materials amenable to substitution, the substitutes can be used without significant delay. Thus, any costs associated with using substitutes for those materials (beyond the costs of the strategic materials planning process, of which this analysis is a part) can be deferred until the onset of the crisis or conflict requiring their use. That also means that those costs might never be incurred at all if the crisis or conflict (here the Base Case Scenario) never occurs. This is a significant advantage for substitution as a shortfall mitigation measure relative to some other measures like stockpiling. The analysis of the utility of substitution in the section above, in fact, takes this approach. It shows that about 39 percent of the 2013 NDS Base Case scenario civilian shortfall could be mitigated with no pre-crisis/conflict expenditures or consequences (beyond the strategic materials planning process) by or to either the government or the private sector.

Second, regarding the bearer of the costs and consequences of using substitutes (whether those costs occur during the crisis/conflict or before), the government could choose to allow them to be borne by the product manufacturers and users, i.e., the private sector, or it could choose to bear some or all of those costs itself by subsidizing the use of substitutes. If it chose the former, the only real cost the government would incur would be the cost of the strategic materials planning process in which it would identify the materials for which it would allow the country to rely on substitutes to meet demand. If it chose the latter, then it could also choose which costs to subsidize. Those costs could range from the costs of materials relative to pre-crisis/conflict prices, to the costs of new enabling capabilities like production facilities, to the costs of mitigating consequences of using substitutes, like potential environmental impacts.

To summarize, this analysis indicates that the government could rely on the use of substitutes to mitigate about 39 percent of the civilian material shortfalls of the 2013 NDS Base Case scenario, with no expenditure prior to the onset of the conflict beyond the cost of the strategic materials planning process. During the conflict, the government could choose to subsidize the increased costs of substitute materials relative to the shortfall materials' peacetime costs, the costs of any enabling capabilities required to use the substitutes, and the costs related to mitigating the consequences of using the substitutes if any. Or it could choose to allow those costs to be borne by the private sector. Because all of the available substitutes for the 2013 Base Case scenario evaluated here would be mitigating civilian rather than defense shortfalls, no substitutes would be used to cover defense demand in the scenario and thus the government would not have to bear any costs of the use of substitutes directly.[5]

Conclusion

Substitution has significant potential to mitigate material shortfalls during a conflict or supply disruption crisis. Often, alternatives are available to meet material demands but under ordinary circumstances, they are not used because they are somewhat suboptimal from the market's perspective on cost-effectiveness—they are more expensive than the material currently in use for the application in question, they do not perform quite as well as the material currently in use, or their usage imposes other avoidable costs like product operating costs or energy usage costs. Nevertheless, during a conflict or crisis, when materials may not be available as they are today, substitute materials or substitute products can be available to meet demands. Analysis of the shortfall materials of the 2013 NDS Base Case scenario shows that substitutes could mitigate shortfalls, at least in part, for many of them. Furthermore, because additional capabilities to enable the use of those substitutes are largely unneeded, no expenditures before the conflict or crisis (beyond those for the strategic materials planning process) need be made for them to be available. Further still, because the great majority of the demand that would be met by substitutes in the 2013 NDS Base Case scenario would be civilian demand, the government could choose to allow the private sector to bear nearly all of the additional costs associated with the use of substitutes during the scenario. This makes substitution a particularly powerful material shortfall mitigation option, where it is available, compared to other options like stockpiling.

5 Potential substitutes for four materials exhibiting defense shortfalls are discussed in Appendix 5. If such substitutes were used in the event of a crisis, the costs of using them would be borne by the government.

Appendix 10
Extra Buys

Introduction

This appendix concerns the shortfall mitigation option that involves buying extra material. First, the concepts and their implementation in the modeling process are explained. Then, an example is provided. Finally, the effects on the Base Case shortfalls that result from allowing extra material buys are presented.

Background, Concepts, and Modeling

Market Shares

The United States is not in general the only country that demands a material. In a conflict scenario, allies have legitimate uses of the material, and unfriendly countries might be able to outbid the United States for some of it on world markets. Thus the United States cannot necessarily obtain all the foreign supply. In the context of the models, the term “market share” factor refers to the fraction of foreign supply the United States can obtain. The market shares for the different materials are inputs to the model; they vary by material but not country. The most commonly used approach for developing market shares is to take the ratio of the U.S. gross domestic product (GDP) to the total of the GDPs of all the countries, including the United States, that demand that material. (GDPs of countries involved in the conflict scenario can be decremented to account for war damage.[1]) An alternative way of computing the market share, which is used for some materials, is to take the ratio of (current) U.S. imports to non-U.S. production. But current level of imports, in peacetime, might underestimate the amount of material the United States could get if it really started bidding for it. GDP can be considered a measure of the ability of the United States to bid, relative to other countries.

Note that the market share factor operates in addition to the other foreign supply decrement factors of war damage, infrastructure reliability, anti-U.S. sentiment, and shipping losses. In the Base Case data, most of the market shares are in the range of 20 percent to 30 percent.

---

[1] The Stockpile Sizing Module computer program (see Appendix 7) can be set to accept data on GDPs, demander countries, and war damage adjustment factors, and then to compute the resultant GDP ratios and use them as the market shares.

Estimated Production vs. Unused Capacity

It is often the case that material is not being produced at full capacity. The amount actually produced is uncertain and often dependent on economic factors, while the amount of capacity, including production plus unused capacity, is more stable. The specialists at the U.S. Geological Survey provide estimates of future capacity, for each producing country, for a number of years into the future. In this context, capacity represents readily available extra production that can be brought online in a few months with little or no extra investment—perhaps simply by adding an extra shift.

In an emergency scenario in which demand for the material increases, it is assumed that producers can and will ramp up to their full capacity, and that that extra production will be available for sale. In the Base Case, the ramp-up time is set to six months, and the full capacity remains available for the rest of the scenario. It has generally been assumed that the United States can access some of the previously-unused foreign capacity that becomes available through ramp-up. The Base Case assumption is that the United States can access its market share percentage of the total capacity available.

The Extra Buy or Expanded Market Share Concept

It certainly is reasonable that in a national emergency scenario, U.S. funds might be available to pay foreign producers to utilize some or all of their excess capacity, with the proviso that the United States obtains preferential access to the output of the portion of capacity that previously was unutilized. This concept can be referred to by the phrases "extra buy" or "expanded market share." The implementation in the modeling process is as follows.

Consider the projected available supply capacity for a given material from a given country in a given year. Partition this capacity into an amount corresponding to production and an amount corresponding to unused capacity. Of the former part, the United States is assumed to be able to get the "regular" market share, as described above. Of the unused capacity, the United States gets a share value that is *x percent* of the way between the regular share and all of the unused capacity. This share value can be denoted the expanded market share. The portion of the unused capacity that the United States gets, above the regular market share, can be thought of as an "extra buy" of material.

The value x is an input to the model that does not depend on material or country. It can vary from 0 to 100 percent. A value of zero for x corresponds to no expanded market share, the regular share ratio being used across the board. In the Base Case, x was set to zero. A sensitivity case with x set to 50 percent is discussed later in this appendix.

Example of the Extra Buy Concept

An example might make the procedure clearer. Figure 10-1, below, provides an illustration of the extra buy concept. The computations are performed separately for each combination of material, country, and year, so imagine Figure 10-1 as treating one such combination. Assume that the peacetime production would be estimated at 600 tons but that 400 tons of extra, previously-unused capacity are available that year. Let the regular market share be 25 percent. In an emergency, the full capacity of 1,000 tons is assumed to be potentially available on world markets, but not necessarily to the United States. Without the extra buy, the modeling process postulates that the United States would be able to obtain 25 percent of 1,000 tons, or 250 tons. This could be partitioned as 150 tons of the estimated production plus 100 tons of the previously-unused capacity. Using the expanded market share, with a parameter x equal to 50 percent, the total U.S. share of the 400 tons corresponding to previously-unused capacity would be $0.25 + 0.5 \times (1 - 0.25)$, or 62.5 percent (i.e., 250 tons). The idea is to go halfway between the regular market share and getting all of the previously unused capacity. This share of 62.5 percent can be partitioned as the regular share plus the extra share, i.e., 25 percent plus 37.5 percent. The amount 37.5 percent of the 400 tons of previously-unused capacity, i.e., 150 tons, can be considered the amount of extra buy.

The different rectangles in the figure show the partitioning of the total capacity into the various quantities of interest. The total amount the United States obtains is the sum of:

- its regular share of estimated peacetime production (150 tons),
- its regular share of previously-unused capacity (100 tons).
- the extra buy amount (150 tons).

In the example, this adds up to 400 tons as opposed to 250 if the extra buy option had not been allowed. (This amount might then be subject to conflict-related decrements such as war damage, as mentioned earlier.)

The previously-unused capacity is to be regarded as the previously-unused capacity that is potentially available on the world markets *in the particular year under consideration.* During the first year of the scenario, it might take some time for a producer to ramp up to capacity, so the previously-unused capacity that is potentially available in the first year might be less than that in subsequent years.

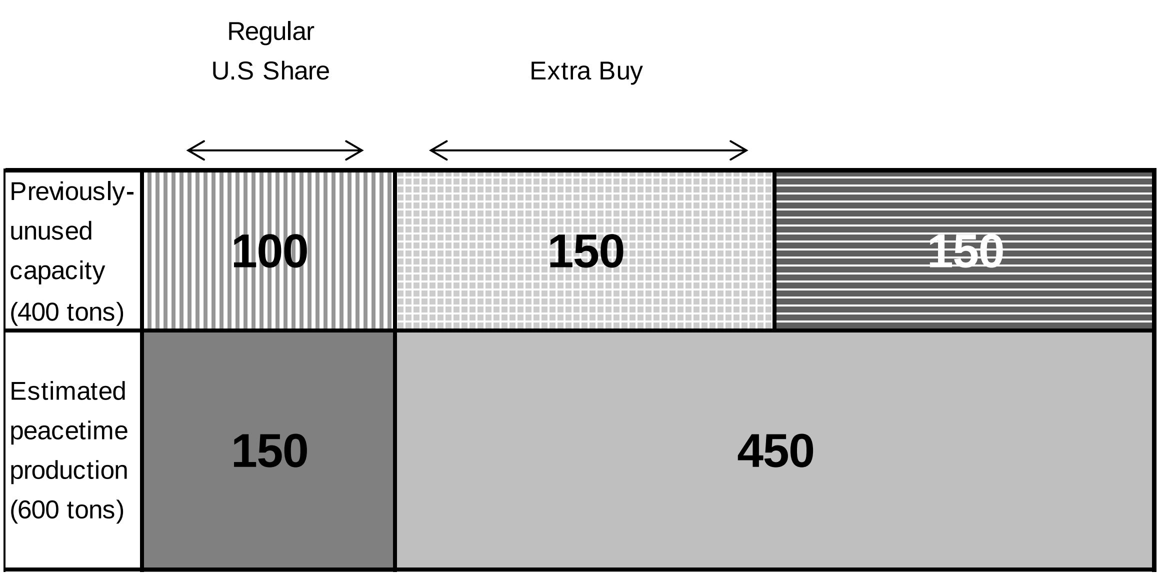
Figure 10-1 Expanded Market Share Concept: Preferential U.S. Access to Foreign Unused Capacity

Parameters	Example value
Total capacity	1,000 (tons)
Estimated peacetime production	600
Previously-unused capacity ready for use	400
Regular U.S. market share	25%
Expansion factor	50%

Total U.S. share of previously unused capacity = .25 + .5*(1-.25) = .625

Extra buy percentage = .625 – .25 = .375

	(Regular) U.S. share of estimated production	.25*600	150
	Share of estimated production going to other countries	.75*600	450
	Regular U.S. share of previously-unused capacity	.25*400	100
	Extra buy = additional U.S. share of previously-unused capacity	.375*400	150
	Unused capacity that might remain unused or go to other countries	.375*400	150
	Total to U.S.	150+ 100+ 150	400



(indicated tonnage amounts are proportional to the areas of the rectangles)

Effect of Extra Buys on 2013 Base Case

A supply-demand comparison was performed (via the Stockpile Sizing Module) using the Base Case supply and demand data but allowing an extra buy of foreign supply with the expansion parameter set to 50 percent (the model would allow setting it to 100 percent, but this was deemed unrealistic and too risky). Table 10-1 shows the Base Case shortfalls, the shortfalls in the extra buy case, and the difference in shortfall, which can be attributed to the extra buy. As in the Base Case, the shortfalls in the extra buy case all occur in the first year of the scenario and all represent unmet civilian demand. (Table 10-1 does not include the extrinsically specified stockpile goal for beryllium metal.)

The overall shortfall value decreases from $1.2 billion to $579 million—a reduction of over 50 percent. For three materials—acid-grade fluorspar, manganese metal, and tin—the shortfall is completely eliminated. But for seven materials (five of which are rare earths) allowing the extra buy option does not affect the Base Case shortfall at all. This is because in the current databases future production of these materials is estimated to be at capacity, so there is no predicted unused capacity for the United States to tap.

Table 10-1. Effect of Extra Buy on Base Case Material Shortfalls*

		Base Case Shortfalls		Shortfalls With Extra Buy		Shortfall Reduction due to Extra Buy	
Material	Units	in units	in $M	in units	in $M	in units	in $M
Aluminum Oxide Fused Crude	short tons	231,485	131.67	205,986	117.17	25,498	14.50
Antimony	short tons	22,575	182.04	15,195	122.53	7,379	59.50
Bismuth	pounds	3,629,659	39.59	2,028,793	22.13	1,600,866	17.46
Chromium Metal	short tons	718	10.68	718	10.68	0	0.00
Dysprosium	MT Oxide	47	21.64	47	21.64	0	0.00
Erbium	MT Oxide	124	12.43	124	12.43	0	0.00
Fluorspar Acid Grade	short tons	56,322	21.54	0	0.00	56,322	21.54
Gallium	kilograms	17,686	10.48	13,750	8.15	3,936	2.33
Germanium	kilograms	28,888	35.66	21,605	26.67	7,284	8.99
Manganese Metal-Electrolytic	short tons	7,406	22.96	0	0.00	7,406	22.96
Scandium	KG Oxide	572	0.77	572	0.77	0	0.00
Silicon Carbide	short tons	81,869	93.88	62,715	71.91	19,154	21.96
Tantalum	pounds Ta	623,307	42.07	23,307	42.07	0	0.00
Terbium	MT Oxide	7	7.16	7	7.16	0	0.00
Thulium	MT Oxide	20	3.31	20	3.31	0	0.00
Tin	metric tons	19,428	416.09	0	0.00	19,428	416.09
Tungsten	pounds W	11,288,268	84.26	4,311,920	32.19	6,976,348	52.08
Yttrium	MT Oxide	1,899	85.17	1,782	79.94	117	5.24
Total $M Value			1,221.41		578.75		642.66

*Does not include extrinsically specified stockpile goal for beryllium metal.

For most of the materials, the increased amount of material supply that arises from the extra buy is not enough to eliminate the Base Case shortfalls. But as noted above, for three materials it is enough–and the supply increase in the first scenario year exceeds Base Case shortfall amount. Table 10-2 shows the two quantities for these materials. This distinction is important because the results reported in Table 10-1 assume that the attempts to buy extra amounts of material all succeed perfectly. When evaluating the effectiveness of extra buys as a shortfall mitigation option, it might be desirable to estimate or postulate a probability of success of the extra buy option and only count on that fraction of the extra buy being available (over and above all reliability decrements). Appendix 11 describes how this idea is implemented in the analysis for shortfall mitigation.

Table 10-2. Shortfall Difference and First Year Supply Increase for Selected Materials

Material	Units	Shortfall Difference (equals Base Case shortfall)	First Year Supply Increase From Extra Buy
Fluorspar Acid Grade	short tons	56,322	184,201
Manganese Metal-Electrolytic	short tons	7,406	13,507
Tin	metric tons	19,428	22,013

Appendix 11
Mitigation Estimates

Introduction

This appendix explains the estimation of the effectiveness of the options postulated for mitigating the risk to the nation from strategic material shortfalls. It explains the process used to assess the probability of success of shortfall mitigation options and how these assessment results are used to develop shortfall mitigation strategies as presented in Figure 4, *DoD's Proposed Mitigation Strategies for 2013 Base Case Shortfall Materials*, of the main report.[1]

Shortfall mitigation estimates were derived from assessing the probabilities that each of five mitigation options will successfully overcome part or all of each of the eighteen non-proprietary Base Case material shortfalls projected for the 2013 National Defense Stockpile NDS Requirements Report.[2] For this purpose, the DoD developed an assessment protocol and utilized a survey instrument for subject matter experts (SMEs) to assess the probability of success of five mitigation options: extra U.S. buys (increased U.S. imports), substitution, decreased U.S. exports, traditional government stockpiling, and buffer stock inventorying.[3]

This appendix will: provide an overview of the five mitigation options; describe the probability of success assessment protocol and survey instrument; explain the process used to compute shortfall mitigation estimates; summarize the probability of success assessment results; and present DoD's recommended mitigation strategies for the eighteen non-proprietary Base Case shortfall materials.

Although five mitigation options were evaluated by using the probability assessment protocol, only four options were considered (excluding buffer stock inventorying) for the

---

1 See page six of the main report.

2 Shortfalls for the 18 non-proprietary materials are estimated to occur only during the first year of the Base Case (2015) and only for civilian demands. (This excludes the extrinsically specified stockpile goal for beryllium metal.) See Appendix 6 for a list of Base Case shortfalls for non-proprietary materials. Defense shortfalls are estimated to occur during every year of the 2013 NDS Base Case (2015 through 2018) for four proprietary materials including three carbon fibers and one specialty rare earth oxide. Shortfall estimates and assessments of related mitigation options for these proprietary materials are addressed separately in Appendix 5.

3 See descriptions of mitigation options in appendices: Appendix 8 (Inventory Methods and Approaches), Appendix 9 (Substitution), Appendix 10 (Extra Buys), and Appendix 16 (Export Reductions).

purpose of developing DoD's recommended mitigation strategies for the eighteen Base Case materials.[4]

Overview of Mitigation Options

Historically, projected NDS material shortfalls have been mitigated through DoD's use of traditional means of government stockpiling. For the purposes of DoD's 2013 NDS Requirements Report, DoD evaluated additional shortfall mitigation options including: extra U.S. buys (increased U.S. imports), substitution, decreased U.S. exports, and buffer stock inventorying. Based on the analysis of these additional mitigation options, these options would be considered before the use of traditional government stockpiling. Each of these mitigation options is briefly discussed. For more details, please see the corresponding appendices.

Extra U.S. Buys (Increased U.S. Imports)

This option relies on increasing the supply of shortfall materials through an increase in U.S. purchases of materials produced by reliable supplier countries during a national emergency. The Base Case currently assumes the United States may buy an estimated "normal market share" (~20 to 30 percent) of current foreign production from reliable countries.[5] The Base Case further assumes the United States may buy an estimated normal market share (~20 to 30 percent) of increased output "ramp-up production" from reliable countries that occurs during the emergency. Ramp-up production is generally defined as the difference between current production and readily available production capacity (i.e., idle production capacity not currently in-use).[6] Readily available production capacity is that which can be brought online within six months from the time of a declared emergency with little to no extra investment other than, for example, factories adding an extra production labor shift.

The extra U.S. buy option posits that the United States can buy a "larger than normal" market share of ramp-up production from reliable foreign suppliers during a national emergency. The larger than normal market share is postulated to be equal to half of the non-U.S. market share. It is assumed that government-to-government pre-arrangements between the United States and key foreign supplier countries would be in-place in advance of an emergency in order to help facilitate extra U.S. buys. Paying

---

[4] Buffer stock inventorying is a relatively new and a special form of government inventorying. It is viewed as a short-term ("bridge the gap") option for smaller amounts of materials versus the use of longer-term traditional government stockpiling for larger quantities of material.

[5] Foreign production includes current production for both the producing country's consumption and exports.

[6] This working definition of ramp-up production capacity is provided by the U.S. Geological Survey (USGS) for use by DoD in estimating material supply for NDS Requirements Report purposes.

premium prices is expected by the United States in an emergency but low to no pre-scenario costs are assumed to occur.

Additional details on this mitigation option are found in Appendix 10.

Substitution

This option relies on a decrease in U.S. demand for shortfall materials through the use of substitute materials anticipated to be available during a national emergency. Substitutes are anticipated to be available for many of the Base Case shortfall materials for some fraction of essential civilian demand. Therefore, material demand for lower priority civilian needs will be reduced via market responses to the shortfalls while available supply of materials for higher priority needs will increase. Substitutes are generally defined as proven substitutes readily available within the first year of the Base Case (2015). They are estimated to exist for most of the 2013 Base Case shortfall materials.

The level of substitutability has earlier been estimated for each shortfall material by SMEs.[7] The amount of demand for shortfall materials that can be reduced by substitutes varies by material (from a low of zero to nearly 100 percent of Base Case demand). Based on prior DoD analyses,[8] the estimated level of substitutability assumes that substitutes: (1) will be available in the market place within the first year of the Base Case; (2) will not require substantial investment or prior federal government market intervention; and (3) will not generate shortfalls of other NDS materials.

Additional details on this mitigation option are found in Appendix 9.

Reduced U.S. Exports

The 2013 Base Case includes the assumption that during a national emergency, the United States will guarantee the availability of materials to produce only 85 percent of those finished goods it export in peacetime (the percentage varies by industry sector). The reduced U.S. exports option tightens this guarantee to only 50 percent in the first year of the scenario except for material used to defense–related exports. It is stressed that the U.S. government would not necessarily take active steps to reduce exports. Rather, it will not guarantee the availability of material to produce a certain portion of goods for export.

Additional details on this mitigation option are found in Appendix 16.

---

7 See Appendix 9 for additional details.

8 See Appendix of the April 18, 2012 draft of the Update to Strategic and Critical Materials 2011 Report on Stockpile Requirements: The Use of Substitution to Mitigate Shortfalls in Strategic and Critical Materials Caused by Material Supply Disruptions.

Traditional Government Stockpiling

A traditional government stockpile is a federally-owned and managed inventory of materials for meeting defense and essential civilian needs during national emergencies. While reliable, traditional government stockpiling takes time to implement. For example, it can take four to eight years to develop NDS material requirements and acquire materials for delivery into U.S. government stockpile storage. For the purposes of assessing the probability of success of traditional government stockpiling for the 2013 NDS Requirements Report, it is assumed that materials needed for stockpiling will already be on hand at the start of the Base Case (by 2015).

Additional details on this mitigation option are found in Appendix 8.

Buffer Stock Inventorying

Under this option, the federal government contracts with one or more domestic suppliers to maintain a domestic inventory of specified shortfall materials (e.g., specific quantity, material grade, and form) available to the government during a national emergency. Under this option, suppliers agree to sell material when the government places orders to buy. Unless the government exercises its option to buy, the government does not own the material (i.e., it is vendor owned). It is estimated that the annual costs to the government for paying suppliers to maintain a buffer stock inventory would be approximately 15 percent of the acquisition cost of the material (i.e., what the vendor paid for the material). At the time the government wishes to acquire the material, it must then pay the acquisition cost. Buffer stock inventorying is considered a short-term mitigation option for smaller quantities of material, whereas traditional government stockpiling is considered a longer-term option for larger amounts of material.

Additional details on this mitigation option are found in Appendix 8.

Probability of Success of Mitigation Options: Assessment Protocol and Survey Instrument

To estimate an expected capability of the mitigation options to either increase the supply of shortfall materials and/or lower their demand, DoD convened a panel of 37 SMEs and elicited their judgments as to the probability of success of each of five mitigation options (independent of each other) to reduce some or all of the 18 Base Case material shortfalls.[9] The probability of success of each mitigation option was applied to

[9] Survey participants included public and private sector specialists from diverse disciplines including military planning and national security policy, economics and commodities, defense industrial base and acquisition programs, materials science and geology, and defense logistics and global supply chains. SMEs included representatives from various organizations within the Office of the Secretary of Defense, the Joint Staff, Defense Agencies, the U.S. Geological Survey (USGS), Federally Funded Research and Development Centers, and academia.

the initially estimated capacity of the option to mitigate the shortfall of each shortfall material to yield the quantity of material that each option would be expected to produce or make available during the Base Case scenario.

The assessment protocol also allowed each SME to estimate his or her level of confidence regarding his or her estimate of the probability of success of each mitigation option. The level of confidence estimates were used to calculate confidence-weighted probabilities of success for each mitigation option for the shortfall for each of the Base Case shortfall materials.

In the case of the extra U.S. buy, substitution and reduced U.S. exports mitigation options, an initial mitigation capacity was pre-calculated (estimated) and provided to SMEs to assess. These pre-calculations were based on supply and demand data for each shortfall material and various DoD-approved Base Case assumptions (e.g., decrements to supply and demand). Initial estimates for substitution were obtained via the research documented in Appendix 9 of this report. Initial mitigation amounts specified for these first three options were generally between 0 and 100 percent of each Base Case shortfall amount.[10] See the example survey question below for the substitution mitigation option. The initial mitigation amount that was pre-calculated for aluminum oxide totaled 231,485 short tons (100 percent of demand) while the initial mitigation amount pre-calculated for antimony totaled 6,289 short tons (28 percent of demand).

The elicited probability of success is treated as a fraction of the initial mitigation amount that can in fact be obtained as discussed later in this appendix. Future assessments will be conducted to elicit probability information using multiple techniques.

[10] In some cases the mitigation capacity was greater than the shortfall amount. That was taken into account in the calculation of the expected shortfall reductions for each option and each material.

Figure 11-1. Substitution Survey Example				
2013 NDS Requirements Report **Survey to Assess the Probability of Success of Base Case Shortfall Mitigation Options**				
Name:				
Instructions: For each of the (18) materials below, assess the probability (%) that a given mitigation option (independent from other options) will successfully mitigate the stated shortfall amount (with 100% being the highest probability score). After assigning your probability score, assign your confidence level in your answer (where 10 is the highest level of confidence). The columns you should complete (E and F) are highlighted in red. Provide a probability score for as many materials as possible. **At minimum, provide an overall (i.e., average) score for the probability of success for this option reducing the shortfalls by the amounts of material listed in Column D (see #19 below).**				
		Option #2: Immediate Substitution		
2013 Shortfall Materials: Listed below are (18) shortfall materials. All shortfalls are for only civilian demands and are estimated to occur in only the first year of the Base Case (2015).	**2013 Base Case material shortfall amount**	**Estimated amount of shortfall reduction by use of this mitigation option and percent of total**	**Your score for the option's probability of success (0-100%)**	**Your level of confidence in your probability score (0-10)**
1. Aluminum Oxide, Fused Crude	231,485 ST	231,485 ST (100%)		
2. Antimony	22,575 ST	6,289 ST (28%)		

In the case of traditional government stockpiling and buffer stock inventorying, the initial mitigation amount was set at 100 percent of the shortfall amount for all of the Base Case materials. See the example survey question below for aluminum oxide and antimony and the initial mitigation amounts for the traditional government stockpiling option.

Figure 11-2. Stockpiling Survey Example				
2013 NDS Requirements Report **Survey to Assess the Probability of Success of Base Case Shortfall Mitigation Options**				
Name:				
Instructions: For each of the (18) materials below, assess the probability (%) that a given mitigation option (independent from other options) will successfully mitigate the stated shortfall amount (with 100% being the highest probability score). After assigning your probability score, assign your confidence level in your answer (where 10 is the highest level of confidence). The columns you should complete (E and F) are highlighted in red. Provide a probability score for as many materials as possible. **At minimum, provide an overall (i.e., average) score for the probability of success for this option reducing the shortfalls by the amounts of material listed in Column D (see #19 below).**				
		Option #3: Traditional Government Stockpiling		
2013 Shortfall Materials: Listed below are (18) shortfall materials. All shortfalls are for only civilian demands and are estimated to occur in only the first year of the Base Case (2015).	**2013 Base Case material shortfall amount**	**Estimated amount of shortfall reduction by use of this mitigation option and percent of total**	**Your score for the option's probability of success (0-100%)**	**Your level of confidence in your probability score (0-10)**
1. Aluminum Oxide, Fused Crude	231,485 ST	231,485 ST (100%)		
2. Antimony	22,575 ST	22,575 ST (100%)		

For each mitigation option for each material, survey participants were asked to first provide their probability of success scores (using a range of 0 to 100 percent where 100 percent was considered most reliable). Survey participants were then asked to report their level of confidence for each of their probability scores (using a scale of 0 to 10 where 10 was most confident). Individual probability scores were then weighted by a survey participant's confidence levels to derive a confidence-weighted probability score for each mitigation option, material-by-material.

For each combination of material and mitigation option, an average confidence-weighted probability score was calculated from the total of scores received (a standard deviation was also calculated to assess the variability across the individual probability scores). The initial mitigation amount for each material was then multiplied by the average confidence weighted probability for each mitigation option to yield an expected mitigation amount. A detailed illustration of this process for estimating expected shortfall mitigation amounts is presented later in this appendix (see antimony example).

Table 11-1 presents the probabilities of success obtained through the survey, material-by-material and across all eighteen shortfall materials overall.

Table 11-1. Average Confidence-Weighted Probability of Success Scores by Mitigation Option (Percentage)

Shortfall Material	Traditional Government Stockpiling	Buffer Stock	Substitution	Extra U.S. Buys	Reduced U.S. Exports
Aluminum Oxide Fused Crude	77	68	69	73	46
Antimony	75	70	59	59	41
Bismuth	76	69	65	61	45
Chromium Metal	83	73	*	**	46
Dysprosium	74	49	45	**	39
Erbium	70	46	*	**	41
Fluorspar Acid Grade	77	73	66	75	44
Gallium	77	69	55	67	41
Germanium	78	71	*	64	44
Manganese Metal–Electrolytic	75	70	0	74	45
Scandium	74	47	88	**	37
Silicon Carbide	76	70	64	71	51
Tantalum	77	69	*	**	41
Terbium	77	50	49	**	40
Thulium	70	44	*	**	40
Tin	73	69	67	78	44
Tungsten	77	68	57	62	46
Yttrium	71	46	48	54	35
Overall, across all materials	**78**	**71**	**59**	**64**	**42**

* The probability of success survey was sent to the SMEs before the fractions of demand amenable to substitution for these materials were developed (see Appendix 9), so the SMEs could not be asked about them. The overall probability of success was used for these materials.

** There is no extra buy amount available for these materials because the full production capacity is estimated to be in use during the scenario period. The probability of success is therefore irrelevant, and was not solicited.

In addition to providing probability scores for all five mitigation options material-by-material, respondents were asked to enter an "overall" probability score across all eighteen shortfall materials. This overall score is intended to reflect the general (average) probability that this measure, if invoked, will reduce the shortfalls by the amounts given. For those not sufficiently knowledgeable with assigning probability scores for all eighteen materials, the survey instructed respondents to provide probability of success scores for as many materials as possible as well as provide an overall probability score for each of the five options.

To assist SMEs in assessing the probability of success of mitigation options and evaluating the mitigation capacity for each of the study materials, the assessment protocol included a number of survey aids including: (1) definitions of mitigation options; (2) 2013 NDS Base Case assumptions regarding the use of mitigation options; (3) descriptions of shortfall materials' application areas; (4) Base Case shortfall estimates and their fraction of essential civilian demand; (5) information about the substitutability potential of the shortfall materials; and (6) available USGS commodities information for the shortfall materials.

Given the relative importance of the of Base Case assumptions, and other considerations DoD presented to the SMEs as they assessed probability scores and score confidence levels, DoD provided the following caveat to survey participants: if a survey participant has difficulty accepting a Base Case assumption, SMEs were instructed to identify it and report what difference (if any) it makes to their probability assessments. This survey provision provided DoD with useful insights into important factors (e.g., supply, demand and mitigation potential) that can affect the effectiveness of mitigation options.

Computing Amounts and Proportions of Different Stockpile Mitigation Options

After the probabilities of success of the different mitigation options have been determined based on the survey results, a procedure is performed to determine a mitigation strategy, i.e., a mix of mitigation options to ameliorate the shortfall. A different mitigation strategy is developed for each shortfall material. This section describes the procedure.

General Description of Procedure

First, each of the mitigation options (extra buy, substitution, and reduced exports) is considered separately. Each option results in either an increase in available supply or a decrease in demand, under the assumption that the option is perfectly successful. Because all Base Case shortfalls occur only in the first year, only the first year values are considered (additional methodology is necessary to consider time streams of supply or demand changes).[11] The supply increase or demand decrease values are multiplied by the

[11] These first year supply increases or demand decreases appear, material by material, in Appendix 10 for the extra buy option, in Appendix 9 for the substitution option, and in Appendix 16 for the reduced exports option.

probability of success (of the given option, for the given material) to yield expected supply increases or demand decreases available. These expected available amounts can then be applied to offset the Base Case shortfall.

The three mitigation options are then considered in a particular order. For this report, they are considered in the order extra buy first, then substitution, then reduced exports. The rationale for this order is explained in the main report (Recommendations section). The expected available amounts from each option are subtracted, in turn, from the original shortfall amount. That is:

- The expected supply increase amount from the extra buy option is subtracted from the original shortfall and the remaining shortfall is computed.
- If the remaining shortfall is greater than zero, then the expected demand decrease amount from the substitution option is subtracted from the remaining shortfall.
- If there still is residual shortfall, the expected demand decrease amount from the reduced exports option is subtracted from the residual shortfall.

Whatever shortfall remains is to be addressed by stockpiling. Existing NDS inventory, if any, is subtracted from that remaining shortfall amount. The difference must be satisfied by new stockpile acquisitions. To allow for stockpile probability of failure, plan to use or attempt is made to acquire a correspondingly larger amount than that difference. This analysis considers traditional stockpiling rather than buffering because traditional stockpiling is almost always more cost-effective in scenarios like the Base Case (see Appendix 12).

Note that the stockpiling option is performed in the present or near future, regardless of whether or not the emergency situation occurs. But the extra buy, substitution, and reduced exports options are implemented only if and when the emergency situation occurs. The idea is that the expected amounts of material obtained from the latter three options, plus the expected amount obtained from stockpiling, will sum to the shortfall amount. Because of the probability of failure, obtaining the expected amount (for each option) means that one must plan to obtain a correspondingly larger amount of material.

Example

An example might make the procedure clearer. Consider the case of antimony, which has a Base Case shortfall of 22,575 tons. The results of the individual mitigation options appear in Table 11-2.

Table 11-2. Results of Shortfall Mitigation Options for Antimony (values in short tons)

Mitigation Measure	Additional Supply or Reduced Demand with 100 Percent Success	Probability of Success	Expected Additional Supply or Reduced Demand	Expected Amount to Apply to Shortfall	Shortfall Remaining	Amount to Plan to Obtain
(at outset)					22,575	
Extra Buy	7,379	0.59	4,321	4,321	18,254	7,379
Substitution	6,638	0.59	3,918	3,918	14,336	6,638
Reduced Exports	5,805	0.41	2,372	2,372	11,964	5,805
Stockpiling	(unlimited)	0.75	(unlimited)	11,964	0	15,955

After all three mitigation options have been considered, there still is a shortfall of 11,964 tons remaining, which is to be addressed via stockpiling. There is currently no antimony in the NDS, so this must all be acquired by new purchase. Given a 75 percent success probability of stockpiling, an amount of 11,964/0.75, or 15,955 tons of antimony should be planned to be purchased for the stockpile.

The mitigation strategy for antimony is thus as follows.

- Undertake to acquire an extra buy of 7,379 tons; expect to obtain 4,321 tons through this mitigation option (where 4,321 = 0.59×7,379).
- Undertake to substitute 6,638 tons; expect that 3,918 tons (i.e., 0.59×6,638) will be substituted.
- Undertake not to guarantee material in exported goods by an amount of 5,805 tons; expect to free up 2,372 (i.e., 0.41×5,805) tons this way.
- Plan to acquire 15,955 tons of material for the stockpile; expect that 11,964 (i.e., 0.75×15,955) tons of material will be available via stockpiling.

Note that:

- The sum of the expected amounts obtained through the various options, i.e., the sum of the quantities 4,321, 3,918, 2,372, and 11,964, equals the original shortfall amount of 22,575 tons.
- The amounts that are *planned* to be obtained (7,379, 6,638, 5,805, and 15,955) are in relative proportions 21 percent, 19 percent, 16 percent, and 44 percent. These percentages are what are shown in Figure 4 of the main report, which is reproduced as Figure 11-3, below.
- In the case of antimony, the amounts planned to be obtained (last column of Table 11-2) equal the supply or demand changes with 100 percent success (first column of Table 11-2). This is because even if all three mitigation

options are used as fully as possible, a shortfall still remains. It is possible that a mitigation option might not have to be used fully. For example, if extra buys and substitution cover most of the shortfall, only part of the demand decrease from the reduced exports option might need to be realized.

Figures and Tables

For each shortfall material, Figure 11-3 shows the relative percentages of the material to plan to obtain via the various mitigation options. As noted above, these percentages are one of the end results of the mitigation computation, and Figure 11-3 is the same as Figure 4 in the main report.

Figure 11-3. DoD's Proposed Mitigation Strategies for 2013 Base Case Shortfall Materials

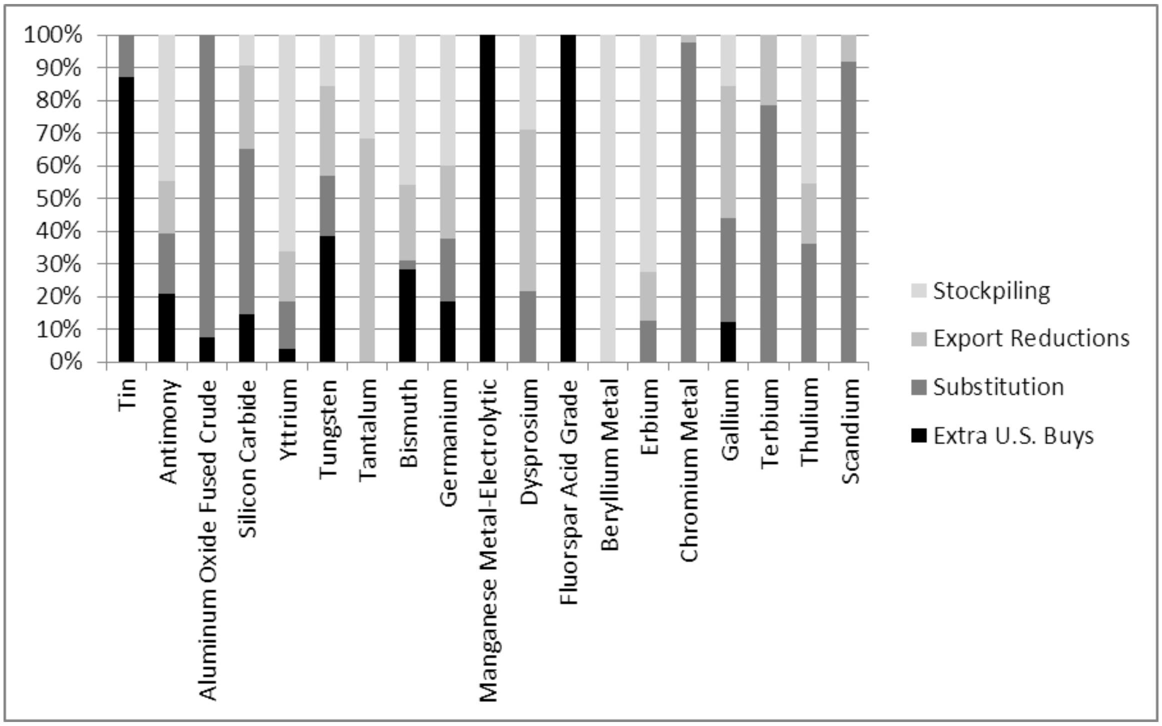


Table 11-3 shows, for each shortfall material, the amounts of material to plan to obtain by the various mitigation options. Table 11-4 shows the corresponding amounts of material that are expected to be obtained. In general, the values in Table 11-4 are the values in Table 11-3 multiplied by the success probabilities from Table 11-1.[12] These tables include the extrinsically specified stockpile amount of 52 short tons of beryllium metal, but that was not computed by the procedure described above. Table 11-5 shows two different sets of quantities for each material. The first set is the decrease in demand

[12] The exception is in the "stockpiling" columns for materials that currently have NDS inventory: beryllium metal, germanium, and tungsten.

or increase in supply, given that the option is perfectly successful. The values in the second set are the corresponding values in the first set multiplied by the appropriate probabilities of success. (The values in the first set might be larger than the values in Table 11-3, because not all of the extra material might be needed to ameliorate the shortfall. Similarly, the values in the second set might be larger than the values in Table 11-4.)

Table 11-3. Amounts of Shortfall Materials to Plan to Obtain via Indicated Mitigation Options
(includes stockpile inventory where applicable)
(amounts in units)

Material	Units	Extra Buy	Substitution	Reduced Exports	Stockpiling	Total
Aluminum Oxide Fused Crude	short tons	25,498	307,858	0	0	333,356
Antimony	short tons	7,379	6,638	5,805	15,954	35,776
Beryllium Metal	short tons	0	0	0	52	52
Bismuth	pounds	1,600,866	140,589	1,295,234	2,587,525	5,624,214
Chromium Metal	short tons	0	1,193	29	0	1,222
Dysprosium	MT Oxide	0	20	46	27	93
Erbium	MT Oxide	0	24	29	140	193
Fluorspar Acid Grade	short tons	75,077	0	0	0	75,077
Gallium	kilograms	3,936	10,418	13,140	5,125	32,619
Germanium	kilograms	7,284	7,722	8,836	15,828	39,670
Manganese Metal-Electrolytic	short tons	10,009	0	0	0	10,009
Scandium	KG Oxide	0	628	56	0	684
Silicon Carbide	short tons	19,154	65,782	32,888	12,325	130,149
Tantalum	pounds Ta	0	0	815,374	378,132	1,193,506
Terbium	MT Oxide	0	12	3	0	15
Thulium	MT Oxide	0	12	6	15	33
Tin	metric tons	22,013	3,294	0	0	25,307
Tungsten	pounds W	6,976,348	3,325,044	5,006,204	2,800,942	18,108,538
Yttrium	MT Oxide	117	455	460	2,039	3,071
Total $M value		713.27	481.25	259.20	376.56	1,830.28

Table 11-4. Expected Amounts of Shortfall Materials Obtained via Indicated Mitigation Options (amounts in units)

Material	Units	Extra Buy	Substitution	Reduced Exports	Stockpiling	Total (equals Base Case Shortfall)
Aluminum Oxide Fused Crude	short tons	18,562	212,923	0	0	231,485
Antimony	short tons	4,321	3,918	2,372	11,964	22,575
Beryllium Metal	short tons	0	0	0	52	52
Bismuth	pounds	983,537	90,714	582,474	1,972,933	3,629,659
Chromium Metal	short tons	0	705	13	0	718
Dysprosium	MT Oxide	0	9	18	20	47
Erbium	MT Oxide	0	14	12	98	124
Fluorspar Acid Grade	short tons	56,322	0	0	0	56,322
Gallium	kilograms	2,656	5,757	5,340	3,933	17,686
Germanium	kilograms	4,649	4,562	3,849	15,828	28,888
Manganese Metal-Electrolytic	short tons	7,406	0	0	0	7,406
Scandium	KG Oxide	0	551	21	0	572
Silicon Carbide	short tons	13,599	42,094	16,802	9,373	81,869
Tantalum	pounds Ta	0	0	331,542	291,764	623,307
Terbium	MT Oxide	0	6	1	0	7
Thulium	MT Oxide	0	7	2	11	20
Tin	metric tons	17,208	2,221	0	0	19,428
Tungsten	pounds W	4,299,459	1,891,508	2,296,359	2,800,942	11,288,268
Yttrium	MT Oxide	63	217	163	1,456	1,899
Total $M value		526.99	306.20	110.90	293.45	1,237.53

Table 11-5. Changes in Material Supply or Demand Under Selected Mitigation Options (values in units)

		Increased supply or decreased demand with 100% success			Expected available increased supply or decreased demand (after multiplication by probability of success)		
Material	Units	Extra Buy	Substitution	Reduced Exports	Extra Buy	Substitution	Reduced Exports
Aluminum Oxide Fused Crude	short tons	25,498	311,726	60,072	18,562	215,598	27,847
Antimony	short tons	7,379	6,638	5,805	4,321	3,918	2,372
Bismuth	pounds	1,600,866	140,589	1,295,234	983,537	90,714	582,474
Chromium Metal	short tons	0	1,193	3,320	0	705	1,524
Dysprosium	MT Oxide	0	20	46	0	9	18
Erbium	MT Oxide	0	24	29	0	14	12
Fluorspar Acid Grade	short tons	184,021	852,085	174,638	138,050	562,335	77,370
Gallium	kilograms	3,936	10,418	13,140	2,656	5,757	5,340
Germanium	kilograms	7,284	7,722	8,836	4,649	4,562	3,849
Manganese Metal-Electrolytic	short tons	13,507	0	3,624	9,993	0	1,645
Scandium	KG Oxide	0	628	62	0	551	23
Silicon Carbide	short tons	19,154	65,782	32,888	13,599	42,094	16,802
Tantalum	pounds Ta	0	0	815,374	0	0	331,542
Terbium	MT Oxide	0	12	12	0	6	5
Thulium	MT Oxide	0	12	6	0	7	2
Tin	metric tons	22,013	4,878	14,990	17,208	3,288	6,556
Tungsten	pounds W	6,976,348	3,325,044	5,006,204	4,299,459	1,891,508	2,296,359
Yttrium	MT Oxide	117	455	460	63	217	163
Total $M value		765.78	843.30	750.14	566.27	545.68	327.80

*Beryllium metal is not included above, because its stockpile amount has been extrinsically specified, rather than being determined by the algorithm described in this appendix.

Appendix 12
Risk and Cost Assessment Methods and Findings

Introduction

In order to evaluate the utility of various measures for mitigating potential shortfalls of materials that could occur during a national emergency, DLA Strategic Materials developed a risk assessment and shortfall mitigation cost-effectiveness analytical process. To provide rigor and consistency with other similar federal government analyses, the DLA analytical process was developed following the guidance of Office of Management and Budget (OMB) Circular A-94. Material shortfall mitigation measures like a stockpile inventory or other measures are risk hedging initiatives implemented to mitigate/manage risk in the face of an uncertain future. Therefore, a cost-effectiveness approach, in place of a cost-benefit approach, was used because of the difficulty in monetizing the benefits provided to the government from a materials stockpile inventory.[1] Consistent with the DoD budget cycle, cost and effectiveness are assessed using a five year planning period. The options for mitigating risk associated with possible material shortfalls evaluated in this analysis include two forms of inventories—government stockpiles and buffer inventories—and three other approaches—increased material imports (i.e., extra buys of materials from foreign sources), material substitution, and reduced exports of goods containing shortfall materials.[2] The principal potential cause of material shortfalls considered in this analysis was the 2013 NDS Base Case scenario. As noted elsewhere in this report, the NDS Base Case scenario is the statutorily mandated scenario used by the DoD to estimate requirements for ensuring the supply of important materials to the nation for both defense and essential civilian needs during a military conflict. The approach taken in this analysis is to consider the material shortfalls identified by DLA Strategic Materials in the Base Case, assess the risks they represent, and evaluate the cost-effectiveness

---

[1] "Cost-effectiveness analysis is a less comprehensive technique, but it can be appropriate when the benefits from competing alternatives are the same or where a policy decision has been made that the benefits must be provided." OMB Circular A-94, 5. General Principles. Here, the benefits of the alternatives are comparable in that they all seek to reduce strategic material shortfall risk to an appropriate level.

[2] "Analyses should also consider alternative means of achieving program objectives by examining different program scales, different methods of provision, and different degrees of government involvement. For example, in evaluating a decision to acquire a capital asset, the analysis should generally consider: (i) doing nothing; (ii) direct purchase; (iii) upgrading, renovating, sharing, or converting existing government property; or (iv) leasing or contracting for services." OMB Circular A-94, Five General Principles.

of the identified mitigation measures in reducing the risks associated with the shortfalls.

Outline of Cost-Effectiveness Analysis Process

The materials risk and cost-effectiveness analysis is outlined below; the steps in the analysis are explained in the remainder of this appendix.

- Identify material shortfall risk mitigation measures.
- Analyze risk associated with potential material shortfalls.
- Analyze residual (mitigated) risk associated with materials and mitigation measures.
- Determine risk threshold to ascertain acceptability of mitigation measures.
- Estimate costs of mitigation measures.
- Identify lowest cost acceptable mitigation measure.

Material Shortfall Risk Mitigation Measures

Five options for mitigating material shortfall risk to the nation were considered in this analysis: (1) government stockpiling; (2) government-contracted private buffer inventories; (3) increased material imports (extra buys); (4) material substitution; and (5) reduced exports of goods containing shortfall materials.[3] These options were identified based on DoD experience in assessing and planning to mitigate risks to the nation from the disruption of the supply of strategic and critical materials. The evaluation process for each of these options is described below with respect to its effectiveness, in terms of reducing supply disruption risk to the nation, and with respect to cost, in terms of net present value (NPV).

Material Shortfall Risk Assessment

The first step in the analysis after identifying the shortfall risk mitigation measures to consider is to assess the existing (unmitigated) risk arising out of potential material shortfalls during the NDS Base Case scenario. Risk is taken to be the product of the probability that a material shortfall would occur and the consequence to the nation of the shortfall.

---

[3] Government stockpiling and contracted private buffer inventories are discussed further in Appendix 8. Increased material imports (extra buys) are discussed further in Appendix 10. Material substitution is discussed further in Appendix 9. Reduced exports of goods containing shortfall materials are discussed further in Appendix 16.

$$\text{Shortfall risk} = P_{scenario} \times C_{shortfall}$$

If more than one shortfall-causing scenario was possible or under consideration, then the total shortfall risk would be equal to the risk of the first plus the sum of the marginal risks produced by each additional scenario.[4]

The probability of a shortfall scenario occurring (the NDS Base Case scenario in this analysis) and the consequences of a material shortfall caused by that scenario cannot be measured directly; thus, DLA used expert judgment to ascertain both quantities for this assessment. Such judgment is based on the experts' knowledge of the materials in question and their applications. Experts consulted in the assessment of the Base Case scenario included those from government, academia, and industry.

By way of further explanation, the probability of shortfall used in this analysis is the probability that a scenario would occur that would create shortfalls in materials important to DoD and the nation. The probability of the Base Case is evaluated, by military experts (different from those who evaluated the consequences of the shortfalls) over a specified period of time and can be reduced to the probability per year or per five years that the scenario will occur. The process used to evaluate the probability of the NDS Base Case and other potential shortfall-creating scenarios is set out in the Appendix 12 Annex, *Strategic Risk Assessment*.

Consequences of material shortfalls are the consequences to the nation that would result from an actual shortfall of each material considered in the event of the shortfall-causing scenario (the NDS Base Case in this analysis). Consequences to the nation can be thought of as including military, economic, and diplomatic consequences potentially produced by material shortfalls. In this analytical process, for each material evaluated, consequences are assessed based on the magnitude of the shortfall and the applications in which the material is used. Some applications are more critical than others and thus shortfalls of some materials are more consequential than the shortfalls of others.

The magnitude of a shortfall caused by a scenario is estimated by comparing the available supply of the material to the demands for it. DLA Strategic Materials has a process for estimating material shortfalls that would be caused by specified national emergency and other supply disruption scenarios. That process is outlined in the main body of this report and described in some detail in Appendix 7,

---

[4] This calculation allows for multiple scenarios that could occur during the period of analysis. In application, scenario probabilities are likely to be low and thus this should have little effect on the total risk calculation. Were multiple scenarios to be considered, it should be ensured that risk-creating potential events are not counted more than once in assessing the risk they create.

Shortfall Computation Methodology. The shortfalls it estimated for the NDS Base Case, for both defense and essential civilian applications, are set forth in the main body of this report and in Table 12-3 below.

In this cost-effectiveness analytical process, once the magnitude of the potential shortfall for each material is estimated, the consequences of the shortfall are assessed by experts who consider the magnitude of the shortfall and the applications in which the material is used. To allow assessments to be compared from one material to another, the experts assess the consequences of potential material shortfalls on a common basis using an anchored scale.[5] The process for evaluating material shortfall consequences is explained further in the next section.

Shortfall Consequence Assessments

DLA Strategic Materials convened two panels with a total of 47 strategic materials experts to estimate the consequences arising from each material shortfall identified. The panels were asked to assess, by using calibrated ratio scales (shown in Tables 12-1 and 12-2, below), the consequences that would result to the nation (military, economic, and political, collectively) if each strategic material shortfall were to remain unmitigated during the NDS Base Case scenario. They were specifically asked to consider both the applications in which each material is used and the quantity of each material in shortfall.

The experts were asked to assess both defense and civilian sector shortfalls for each identified material to produce estimates of the consequences of each sector. One end of the ratio scales used for the assessments represented a shortfall of no or essentially no consequences and the other end represented a shortfall of severe consequences. Experts were free to choose any value along the scales based on their judgments. Shortfall consequences could be (and were in several cases) judged to exceed the upper ends of the scales. To help judge the severity of the shortfall consequences, the experts were provided with guidance regarding the severity of material shortfall consequences in three different respects: the size of the shortfall compared to annual demand; the use of the shortfall material in important defense or civilian applications (for defense and civilian shortfalls, respectively); and the impact of the shortfall on sectors of the defense industrial base and the overall economy (for defense and civilian shortfalls, respectively). They were also provided some background information regarding the nature of the

---

5 The scale is based on the severity of material shortfall consequences in three different respects: the size of the shortfall compared to annual defense demand, the use of the shortfall material in important defense applications, and the impact of the shortfall on sectors of the defense industrial base.

scenarios producing the shortfalls and the uses of the materials to help with their assessments. Finally, when making their evaluations, each expert was asked to indicate his or her confidence in his or her rating for each material, on a scale of 0–10 (0 = no confidence, 10 = very high confidence). That was to account for the different levels of expertise with the different materials among the experts present. The scale, the calibration points, and the criteria (for defense and civilian shortfalls) are depicted in Tables 12-1 and 12-2 below.

Table 12-1. Scale Anchor Points and Supplemental Criteria for Evaluating Defense Shortfalls

Rating	Conclusion	Relative Size of the Shortfall (percent of annual demand)	Criticality of Applications	Economic Impact on the Defense Industrial Base
10	Shortfall of severe consequences (military, economic, political, collectively)	25 percent of defense demand[6]	Almost all used in important platforms and munitions or commercial-type applications important to sustaining DoD operations	Harm to defense industrial base noticeable at a national level (i.e., significant economic harm to a recognizable sector that could create a need to rebuild or reconstitute the sector after the shortage)
5	Shortfall of moderate consequences	12.5 percent of defense demand	Roughly half used in important platforms and munitions or important commercial-type applications	Potential for harm to defense industrial base noticeable at a national level.
0	Shortfall of no or essentially no consequences	Near zero	Essentially none used in important platforms and munitions or important commercial-type applications; Use can be foregone for duration of shortfall without adversely affecting DoD operations	Essentially no impact

[6] Based on an assumption about exhaustion of privately held inventories. When inventories are exhausted, shortages will occur at various points along the supply chain and interrupt production of goods or provision of services.

The severity of the consequences was judged based on the worst case of the impacts with respect to the criteria. Thus, for example, if any of the Relative Size of the Shortfall, the Criticality of Applications or the Economic Impact on the Defense Industrial Base were judged to be at the top of their respective scales, then the overall rating for the shortfall was at the top of the overall scale (a rating of 10). The rationale for using a worst case approach is that if by any of those three criteria, the impact of the shortfall was deemed to be severe, and the shortfall was likely, DoD would probably want to mitigate the risk associated with it. As noted above, shortfall consequences could be (and were in some cases) judged to exceed the top of the overall consequence scale. In those cases, the consequence scores were used as provided to calculate shortfall risk (i.e., they were not reassigned a value of 10).

Table 12-2. Scale Anchor Points and Supplemental Criteria for Evaluating Civilian Shortfalls

Rating	Conclusion	Relative Size of the Shortfall (percent of annual demand)	Criticality of Applications	Impact on the U.S. Civilian Economy
10	Shortfall of severe consequences (military, economic, political, collectively)	25 percent of civilian demand[7]	Almost all used in critical civilian applications important to maintaining the competitive strength of the U.S. economy and the health and safety of the population	Harm to U.S. economy at a national level (e.g., significant damage to a key industrial sector that could create a need to rebuild or reconstitute the sector after the shortage, 3 percent increase in U.S. unemployment rate, 3 percent decrease in U.S. GDP growth rate)
5	Shortfall of moderate consequences	12.5 percent of civilian demand	Roughly half used in critical civilian applications	Potential for harm to U.S. economy at a national level
0	Shortfall of no or essentially no consequences	Near zero	Essentially none used in critical civilian applications; Use can be foregone for duration of shortfall without adversely affecting U.S. economy and the health and safety of the population	Essentially no impact

[7] Based on an assumption about exhaustion of privately held inventories. As noted above, when inventories are exhausted, shortages will occur at various points along the supply chain and interrupt production of goods or provision of services.

As with the defense shortfalls, the severity of the consequences were judged based on the worst case of the impacts with respect to the criteria. Thus, for example, if any of the Relative Size of the Shortfall, the Criticality of Applications or the Impact on U.S. Civilian Economy were judged to be at the tops of their scales, the overall rating for the shortfall was at the top of the overall scale (a rating of 10). As noted, shortfall consequences could be (and were in some cases) judged to exceed the top of the overall consequence scale.

The consequence evaluations for each Base Case shortfall are set forth in Table 12-3 below. Ratings provided in Table 12-3 are mean consequences and confidence-weighted consequences. In every case except one, the confidence-weighted consequences were within 10 percent of the mean consequences (and in that one they were within 20 percent). Thus, the confidence weighting had only a small effect on the consequence ratings. Nevertheless, to obtain the most out of the data collected and to recognize the different areas of expertise among the experts who evaluated the shortfalls, the confidence-weighted consequences are used in all further calculations in this report.

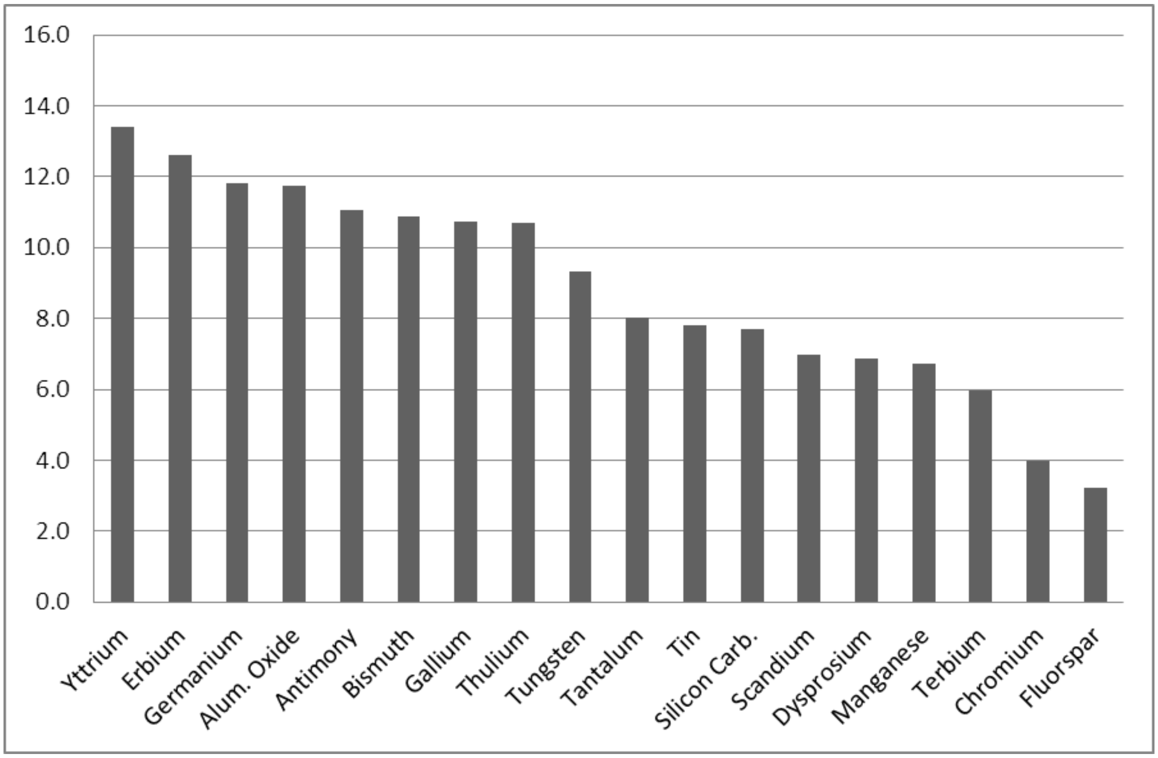
Table 12-3. Approximate Base Case Shortfall Consequences

Material	Shortfall	Units	Mean Estimated Consequences	Confidence-Weighted Mean Consequences
1. Aluminum Oxide, Fused Crude	231,485	short tons	10.5	11.7
2. Antimony	22,575	short tons	10.0	11.1
3. Beryllium (defense)	52	short tons	24.1	25.6
4. Bismuth	3,629,659	pounds	9.8	10.9
5. Chromium Metal	718	short tons	4.2	4.0
6. Dysprosium	47	MT Oxide	6.7	6.9
7. Erbium	124	MT Oxide	11.7	12.6
8. Fluorspar, Acid Grade	56,322	short tons	3.4	3.2
9. Gallium	17,686	kilograms	9.8	10.7
10. Germanium	28,888	kilograms	11.2	11.8
11. Manganese Metal, Electrolytic	7,406	short tons	6.4	6.7
12. Scandium	572	KG Oxide	6.3	7.0
13. Silicon Carbide	81,869	short tons	6.9	7.7
14. Tantalum	623,307	pounds Ta	7.6	8.0
15. Terbium	7	MT Oxide	5.4	5.9
16. Thulium	20	MT Oxide	10.5	10.7
17. Tin	19,428	metric tons	6.9	7.8
18. Tungsten	11,288,268	pounds W	8.5	9.3
19. Yttrium	1,899	MT Oxide	12.6	13.4

All shortfalls are for civilian applications except beryllium, which is for defense.

Many of the shortfalls received high consequences scores because they are large—most of them exceeded 25 percent of annual U.S. demand for the material in question. As shown in the table above, nine out of 19 received confidence-weighted mean consequence scores above 10. Note that beryllium was a defense shortfall. Its consequences should be considered independently of those of the civilian shortfall materials. All consequence scores carry a level of uncertainty revealed by the distributions of the individual consequence assessments; they should be treated as approximate in all cases. The consequences of the civilian shortfalls are displayed in a bar chart below in decreasing order.

Figure 12-1. Base Case Confidence-Weighted Mean Shortfall Consequences



The experts consulted to evaluate the shortfall consequences were drawn from across government, industry, and academia. The specific organizations from which they were drawn are set forth in Table 12-4 below.

Table 12-4. Consequence Evaluation Expert Affiliations

Institute for Defense Analyses (13)
U.S. Geological Survey (11)
Industry (4)
DLA (5)
U.S. Army (5)
Office of the Secretary of Defense (2)
Academia (2)
U.S. Navy (1)
Joint Staff (1)
Defense Contracts Management Agency (1)
Central Intelligence Agency (1)
Oak Ridge National Laboratory (1)

Shortfall Risk Assessments

Once the potential shortfall-creating scenarios were selected for consideration, the probabilities of those scenarios were estimated (see Appendix 12 Annex), the potential material shortfalls created by each scenario were estimated, and the consequences of each shortfall were estimated, the data was used to estimate the existing, unmitigated, approximate shortfall risk for each material. As noted above, the shortfall risk estimates for the NDS Base Case scenario are calculated as shortfall risk = $P_{scenario} \times C_{shortfall}$ and they are set forth below.[8]

Table 12-5. Approximate Base Case Material Shortfall Risks

Material	Shortfall	Units	Estimated Scenario Probability (in 5 years)	Mean Estimated Consequences	Approx. Shortfall Risk
1. Aluminum Oxide, Fused Crude	231,485	short tons	0.0037	10.5	0.043
2. Antimony	22,575	short tons	0.0037	10.0	0.041
3. Beryllium (defense)	52	short tons	0.0037	24.1	0.095
4. Bismuth	3,629,659	pounds	0.0037	9.8	0.040
5. Chromium Metal	718	short tons	0.0037	4.2	0.015
6. Dysprosium	47	MT Oxide	0.0037	6.7	0.025
7. Erbium	124	MT Oxide	0.0037	11.7	0.047
8. Fluorspar, Acid Grade	56,322	short tons	0.0037	3.4	0.012
9. Gallium	17,686	kilograms	0.0037	9.8	0.040
10. Germanium	28,888	kilograms	0.0037	11.2	0.044
11. Manganese Metal, Electrolytic	7,406	short tons	0.0037	6.4	0.025
12. Scandium	572	KG Oxide	0.0037	6.3	0.026
13. Silicon Carbide	81,869	short tons	0.0037	6.9	0.029
14. Tantalum	623,307	pounds Ta	0.0037	7.6	0.030
15. Terbium	7	MT Oxide	0.0037	5.4	0.022
16. Thulium	20	MT Oxide	0.0037	10.5	0.040
17. Tin	19,428	metric tons	0.0037	6.9	0.029
18. Tungsten	11,288,268	pounds W	0.0037	8.5	0.034
19. Yttrium	1,899	MT Oxide	0.0037	12.6	0.050

All shortfalls are for civilian applications except beryllium, which is for defense.

Because all shortfall risks arise out of the NDS Base Case scenario, the risks are simply proportional to the consequences assessed in the previous section. Risk scores are low because of the low probability of the scenario. As noted, shortfall consequences scores are confidence-weighted.

[8] Shortfall risk and risk mitigation assessments for four shortfall materials (three carbon fibers and high purity yttrium) are set forth in the proprietary appendix to this report.

Mitigation Measure Effectiveness Evaluation

After assessing the shortfall risk associated with each material under consideration, the next step in the process was to identify and evaluate the cost-effectiveness of the measures that DoD could use to mitigate the risk. As previously noted, the five mitigation measures that DoD has identified for consideration in this report are: (1) government stockpiling; (2) government-contracted private buffer inventories; (3) increased material imports (extra buys); (4) material substitution; and (5) reduced exports of goods containing shortfall materials. The first step in the evaluation is assessing the effectiveness of the measures. Effectiveness depends on the extent to which each of the measures would reduce the risk associated with each shortfall. Since the mitigation measures cannot affect the probability of a supply disruption scenario occurring in the first place, their effectiveness turns on the extent to which they can mitigate the consequences of each shortfall for which they are considered. Consequences mitigation for each measure is assessed in terms of the likelihood that the measure, if implemented, would eliminate the consequences. Because these measures, except for stockpiling, are new concepts for DoD, there is not a source of historical data from which to calculate or estimate the probability that any measure would succeed or fail to mitigate a potential material shortfall. Thus, DoD used subjective expert judgment for each measure considered for each shortfall. The expert judgment as to the likelihood of success was based on the nature of the relevant materials industry and actors involved in mitigating the shortfall and the control the government has over the means of mitigation. The assessment of the effectiveness of each mitigation measure in reducing the risk from a potential shortfall of each shortfall material in the 2013 Base Case is discussed in Appendix 11, *Mitigation Estimates*.

Calculation of Residual Risk from Material Shortfalls

After the effectiveness of the shortfall mitigation measures are evaluated, their effectiveness in mitigating the risk associated with each material shortfall can be calculated in terms of the residual shortfall risk remaining after they are applied. Residual risk is taken to be proportional to the residual shortfall left after each mitigation measure is applied. Residual shortfall risk is estimated as follows, where residual shortfall risk = *RSR*, shortfall risk = *SR*, the probability of mitigation measure failure[9] = P_f (and the probability of success, P_s, = 1-P_f), the size of the shortfall = *SF*, and the capacity of the mitigation measure = M_{cap}:

---

[9] As noted in Appendix 11, mitigation measures may lack the capacity to mitigate a shortfall even if they work completely as planned because the amount of material they would provide or demand they would relieve would be less than the shortfall amount. Where the product of mitigation

$$RSR = SR[1-(M_{cap}/SF)P_s]$$

For example, as shown in Table 12-6 below, Aluminum Oxide has a shortfall risk of 0.043. The mitigation measure Extra Buy has a capacity relative to the shortfall (M_{cap}/SF) of 0.11.[10] The probability of success of Extra Buy for Aluminum Oxide (P_s) is 0.73. Thus, it is expected that Extra Buy would mitigate 0.11 × 0.73 = 0.0803 (8.03 percent) of the shortfall. Since residual risk is taken to be proportional to the residual shortfall, this measure would reduce risk by 8.03 percent, from 0.043 to 0.040. That 8.03 percent reduction from extra buy is also reflected in Figures 4 and 5 in the main body of the report.

Note that while stockpiling has a probability of success and failure associated with it, it is presumed that sufficient material will be stockpiled, if that option is chosen, to account for that probability and hence reduce residual shortfall risk to zero (see Appendix 11) (stockpiling is treated as essentially having an unlimited capacity to mitigate shortfalls if sufficient material is acquired).

Residual shortfall risk reflects the overall effectiveness of the mitigation measures considered in minimizing risk, for each material analyzed. Residual shortfall risk is the quantity DoD wishes to minimize in planning for potential strategic material shortfalls.

Calculations of residual risk for each Base Case shortfall for each of the four mitigation measures are set forth in Table 12-6 below. Because of the unlimited potential capacity of stockpiling, it is shown as yielding a residual risk of zero for all materials.

---

measure capacity and probability of success is greater than or equal to the shortfall amount, the shortfall is completely eliminated and estimated residual risk is zero.

[10] See also Table 10-1: shortfall reduction due to extra buy (before consideration of probability of success) = 25,498 tons and shortfall = 231,485 tons.

Table 12-6. Shortfall Mitigation Measures and Residual Risks

Material:	**Aluminum Oxide**			
Shortfall Risk	**Mitigation Measure**	**Capacity/ Shortfall**	**Probability of Success**	**Residual Risk**
0.043	Extra Buy	0.11	0.73	0.040
0.043	Substitution	1.35	0.69	0.003
0.043	Reduced Exports	0.26	0.46	0.038
0.043	Stockpiling	Unlim.	0.77	0.000
Material:	**Antimony**			
Shortfall Risk	**Mitigation Measure**	**Capacity/ Shortfall**	**Probability of Success**	**Residual Risk**
0.041	Extra Buy	0.33	0.59	0.033
0.041	Substitution	0.29	0.59	0.034
0.041	Reduced Exports	0.26	0.41	0.037
0.041	Stockpiling	Unlim.	0.75	0.000
Material:	**Bismuth**			
Shortfall Risk	**Mitigation Measure**	**Capacity/ Shortfall**	**Probability of Success**	**Residual Risk**
0.040	Extra Buy	0.44	0.61	0.029
0.040	Substitution	0.04	0.65	0.039
0.040	Reduced Exports	0.36	0.45	0.034
0.040	Stockpiling	Unlim.	0.76	0.000

Table 12-6. Shortfall Mitigation Measures and Residual Risks (continued)

Material:	Chromium Metal			
Shortfall Risk	**Mitigation Measure**	**Capacity/ Shortfall**	**Probability of Success**	**Residual Risk**
0.015	Extra Buy	0.00	0.00	0.015
0.015	Substitution	1.66	0.59	0.000
0.015	Reduced Exports	4.62	0.46	0.000
0.015	Stockpiling	Unlimited	0.83	0.000
Material:	**Dysprosium**			
Shortfall Risk	**Mitigation Measure**	**Capacity/ Shortfall**	**Probability of Success**	**Residual Risk**
0.025	Extra Buy	0.00	0.00	0.025
0.025	Substitution	0.42	0.45	0.021
0.025	Reduced Exports	0.98	0.39	0.016
0.025	Stockpiling	Unlimited.	0.74	0.000
Material:	**Erbium**			
Shortfall Risk	**Mitigation Measure**	**Capacity/ Shortfall**	**Probability of Success**	**Residual Risk**
0.047	Extra Buy	0.00	0.00	0.047
0.047	Substitution	0.20	0.59	0.041
0.047	Reduced Exports	0.23	0.41	0.042
0.047	Stockpiling	Unlimited	0.70	0.000
Material:	**Fluorspar**			
Shortfall Risk	**Mitigation Measure**	**Capacity/ Shortfall**	**Probability of Success**	**Residual Risk**
0.012	Extra Buy	3.27	0.75	0.000
0.012	Substitution	15.13	0.66	0.000
0.012	Reduced Exports	3.10	0.44	0.000
0.012	Stockpiling	Unlimited	0.77	0.000
Material:	**Gallium**			
Shortfall Risk	**Mitigation Measure**	**Capacity/ Shortfall**	**Probability of Success**	**Residual Risk**
0.040	Extra Buy	0.22	0.67	0.034
0.040	Substitution	0.59	0.55	0.027
0.040	Reduced Exports	0.74	0.41	0.028
0.040	Stockpiling	Unlimited	0.77	0.000

Table 12-6. Shortfall Mitigation Measures and Residual Risks (continued)

Material:	**Germanium**			
Shortfall Risk	**Mitigation Measure**	**Capacity/ Shortfall**	**Probability of Success**	**Residual Risk**
0.044	Extra Buy	0.25	0.64	0.037
0.044	Substitution	0.27	0.59	0.037
0.044	Reduced Exports	0.31	0.44	0.038
0.044	Stockpiling	Unlimited	0.78	0.000
Material:	**Manganese Metal**			
Shortfall Risk	**Mitigation Measure**	**Capacity/ Shortfall**	**Probability of Success**	**Residual Risk**
0.025	Extra Buy	1.82	0.74	0.000
0.025	Substitution	0.00	0.00	0.025
0.025	Reduced Exports	0.49	0.45	0.019
0.025	Stockpiling	Unlimited	0.75	0.000
Material:	**Scandium**			
Shortfall Risk	**Mitigation Measure**	**Capacity/ Shortfall**	**Probability of Success**	**Residual Risk**
0.026	Extra Buy	0.00	0.00	0.026
0.026	Substitution	1.10	0.88	0.001
0.026	Reduced Exports	0.11	0.37	0.025
0.026	Stockpiling	Unlimited	0.74	0.000
Material:	**Silicon Carbide**			
Shortfall Risk	**Mitigation Measure**	**Capacity/ Shortfall**	**Probability of Success**	**Residual Risk**
0.029	Extra Buy	0.23	0.71	0.024
0.029	Substitution	0.80	0.64	0.014
0.029	Reduced Exports	0.40	0.51	0.023
0.029	Stockpiling	Unlimited	0.76	0.000
Material:	**Tantalum**			
Shortfall Risk	**Mitigation Measure**	**Capacity/ Shortfall**	**Probability of Success**	**Residual Risk**
0.030	Extra Buy	0.00	0.00	0.030
0.030	Substitution	0.00	0.59	0.030
0.030	Reduced Exports	1.31	0.41	0.014
0.030	Stockpiling	Unlimited	0.77	0.000

Table 12-6. Shortfall Mitigation Measures and Residual Risks (concluded)

Material:	**Terbium**			
Shortfall Risk	**Mitigation Measure**	**Capacity/ Shortfall**	**Probability of Success**	**Residual Risk**
0.022	Extra Buy	0.00	0.00	0.022
0.022	Substitution	1.71	0.49	0.004
0.022	Reduced Exports	1.68	0.40	0.007
0.022	Stockpiling	Unlimited	0.77	0.000
Material:	**Thulium**			
Shortfall Risk	**Mitigation Measure**	**Capacity/ Shortfall**	**Probability of Success**	**Residual Risk**
0.040	Extra Buy	0.00	0.00	0.040
0.040	Substitution	0.60	0.59	0.026
0.040	Reduced Exports	0.30	0.40	0.035
0.040	Stockpiling	Unlimited	0.70	0.000
Material:	**Tin**			
Shortfall Risk	**Mitigation Measure**	**Capacity/ Shortfall**	**Probability of Success**	**Residual Risk**
0.029	Extra Buy	1.13	0.78	0.003
0.029	Substitution	0.25	0.67	0.024
0.029	Reduced Exports	0.77	0.44	0.019
0.029	Stockpiling	Unlimited	0.73	0.000
Material:	**Tungsten**			
Shortfall Risk	**Mitigation Measure**	**Capacity/Shortfall**	**Probability of Success**	**Residual Risk**
0.034	Extra Buy	0.62	0.62	0.021
0.034	Substitution	0.29	0.57	0.029
0.034	Reduced Exports	0.44	0.46	0.028
0.034	Stockpiling	Unlimited	0.77	0.000
Material:	**Yttrium**			
Shortfall Risk	**Mitigation Measure**	**Capacity/ Shortfall**	**Probability of Success**	**Residual Risk**
0.050	Extra Buy	0.06	0.54	0.048
0.050	Substitution	0.24	0.48	0.044
0.050	Reduced Exports	0.24	0.35	0.045
0.050	Stockpiling	Unlimited	0.71	0.000

The table above shows the effect of implementing each of the mitigation measures for each of the Base Case shortfalls. In some cases, mitigation measure effectiveness is limited mostly by its capacity and in others, it is limited mostly by its probability of success. As discussed in Appendix 11, the mitigation measures have different capacities and probabilities of success based on circumstances related to each material.

Considering Risk Mitigation across Shortfall Materials

After the residual risks are calculated for each potential material shortfall and each available mitigation measure, DoD can consider choices regarding which measures to apply to which potential shortfalls. One potential approach in making that choice is to mitigate residual strategic materials risk on a material by material basis by applying a common risk threshold (or maximum risk) to all the materials and choosing a shortfall mitigation measure (or measures) for each material that would reduce risk for each material to a specified level to be determined. That would allow DoD to use the common risk threshold to manage risk from material shortfalls across a range of materials and mitigation measures. In a general sense, this approach would be similar to the risk management approach DoD utilizes with other kinds of risks arising from military threats to U.S. interests—aiming to mitigate risks down to some acceptable level. It is also similar to the approach traditionally taken by DoD to mitigate strategic materials risk, in which material would be recommended for stockpiling to cover all shortfalls identified in the DoD planning process. However, this process allows DoD to consider alternatives to stockpiling that may be able to mitigate risk to an acceptable level at a lower cost. As discussed at the end of this appendix, this approach facilitates making cost-risk tradeoffs by allowing DoD to select the lowest-cost mitigation measure that would meet the risk threshold for each material.[11]

An example of how this approach could be used to consider risk mitigation across shortfall materials is set forth below using aluminum oxide and chromium from above as examples.

[11] As noted at the end of this appendix and as seen in the main body of the report, the approach taken for the FY2013 NDS requirements analysis is to eliminate all expected shortfall risk, e.g., apply shortfall risk mitigation measures until the expected shortfalls of all materials are reduced to zero. Actual risk, albeit low, would remain, arising from the uncertainties associated with risk estimates and the reliabilities of risk mitigation measures. The following discussion in this section also illustrates how the Department could choose among shortfall mitigation option if it also chose to accept different (higher) levels of shortfall risk.

Table 12-7. Illustration of Risk Mitigation Across Shortfall Materials

Material:	Aluminum Oxide			
Shortfall Risk	**Mitigation Measure**	**Capacity/ Shortfall**	**Probability of Success**	**Residual Risk**
0.043	Extra Buy	0.11	0.73	0.040
0.043	Substitution	1.35	0.69	0.003
0.043	Reduced Exports	0.26	0.46	0.038
0.043	Stockpiling	Unlimited	0.77	0.000
Material:	**Chromium Metal**			
Shortfall Risk	**Mitigation Measure**	**Capacity/ Shortfall**	**Probability of Success**	**Residual Risk**
0.015	Extra Buy	0.00	0.00	0.015
0.015	Substitution	1.66	0.59	0.000
0.015	Reduced Exports	4.62	0.46	0.000
0.015	Stockpiling	Unlimited	0.83	0.000

If, in this example, a common risk threshold of 0.005 was applied to both materials, the following mitigation measures would mitigate shortfall risk to that threshold: substitution and stockpiling for aluminum oxide and substitution, reduced exports, and stockpiling for chromium. The next step in the analytical process is to consider the impact of cost on choices of shortfall mitigation measures.

Cost Comparison across Mitigation Measures

The next step in the process after evaluating the effectiveness of potential strategic materials risk mitigation measures is to estimate their costs so that their cost-effectiveness can be evaluated. OMB A-94 Circular stipulates that net present value is the standard criterion for comparing government policies and/or programs. NPV is defined as the "discounted monetized value of expected net benefits (i.e. benefits minus costs)"; its equation is seen below, where i = discount rate and t = year index.[12]

$$NPV = \frac{(Benefits - Costs)}{(1+i)^t}$$

[12] If benefits and costs occur at different time periods, then this calculation is repeated for each relevant period and summed over all of them to yield total NPV.

The context within which we measure costs and benefits for material shortfall mitigation measures is the statutorily mandated NDS Base Case scenario, described in 50 United States Code, section 98. Therefore, our analysis uses the probability of the Base Case, as determined by subject matter experts (SMEs) in the risk analysis, to weight certain expenditures and benefits. Hence, the criterion we use to compare costs across policies is an expected NPV, where costs and benefits are weighted by the probability of a given scenario (in this case, the Base Case). The exact details of these weighting schemes are dependent on the specific mitigation measures in consideration (discussed in the following sections).

The discount rate in our analysis (0.4 percent) is taken from OMB A-94 Circular. It represents the real annual discount rate to be applied during a period of analysis of five years. Therefore, the criterion used in the subsequent cost analysis is expected NPV, given by the following equation:

$$Expected\ NPV = \sum_{t=0}^{4} \frac{Expected\ Net\ Cash\ Flow}{(1+i)^t}$$

This discount factor was applied to the expected net cash flow for each year of the scenario in the estimation of the NPV of each shortfall mitigation option discussed below. All calculations in this report are performed with real dollars and expressed in current year (2012) terms.

Cost of Stockpiling Materials

The cost of stockpiling materials is primarily dependent on the amount of material to be inventoried, market price at the time of acquisition, and on-going storage and operation costs. Stockpiling is the only risk mitigation measure whose expenditure could be recouped by the government in the event the material is no longer needed and could be sold. Therefore, a monetized benefit can be included in the calculation of NPV that represents the amount which the government could effectively recoup, weighted by the probability of a conflict not occurring.[13]

Hence, the value of stockpiling can be calculated using the expected net cash flow given in Table 12-8 for each year over a five year planning period. In the following table, x = material amount, MP = market price, S = storage costs, r =

[13] Recoupment of stockpiling costs in the event the scenario occurs and the material is needed to meet defense or essential civilian needs (potentially by selling it to U.S. users) is not addressed as it would require a prediction of stockpile sales policy during an emergency. Nevertheless, the potential impact of considering such possible recoupment is small because the probability of the Base Case scenario is low.

expected recoupment percentage, *FP* = projected future price,[14] and *p* = probability of conflict within five years.

Table 12-8. Expected Net Cash Flow for Stockpiling Materials

Year Index	0	1	2	3	4
Expected Net Cash Flow	$MPx + S$	S	S	S	$S - rFPx(1-p)$

The expected net cash flow is designed to represent the purchase of all material in the first year. If a purchase of this magnitude would negatively impact the market, the acquisition could be spread out over multiple years. As noted above, the appropriate discount factor is applied to the net cash flow in each year in the calculation of NPV for this mitigation measure.

The cost of storage variable, *S*, is included in the expected cash flow of stockpiling a material. For the purposes of this analysis, the operation costs at three government depot sites (Scotia, NY, Warren, OH and Hammond, IN) were considered. Operation costs included leases, security, communications, utilities, vehicles, facility maintenance, equipment maintenance and recapitalization. These operation costs were aggregated and divided by the total indoor square footage (SF) to yield a $/SF/year value for each site. Using the amount of material in consideration, coupled with the density requirement at each site (not to exceed 1000 LB/SF), a total square footage required for each material can be calculated. Hence, the total amount required to store the material amount can be determined for each of the three facilities. The maximum value of these three amounts was used for the storage value in the expected cash flow for stockpiling equation. Overall, the storage costs are a small percentage of the acquisition cost of a material. At each of the three facilities, there is sufficient space for new material storage.

The last quantity to consider in estimating the net cost of stockpiling is the likely price for the material that the government could recoup upon selling it. While the cost of stockpiling is often discussed colloquially in terms of the acquisition cost (suggesting that the value of the material evaporates in storage), in fact, stockpiled materials are durable goods that the government can and does sell after they are no longer needed to mitigate the risk of potential material shortages. The stockpile recoupment price is dependent upon several things, chiefly the

[14] Although the planning period used in this cost analysis is five years, it is recognized that stockpiled material is typically held by the government for longer periods of time. The effect of that on the estimated price the government would realize when selling stockpiled material is taken into account in estimating the future price of the material, *FP*. The longer planning period is also accounted for in estimating the NPV of future stockpile sales (recoupment).

difference in prevailing market price for each quantity of material stockpiled between the time of acquisition and sale. Such differences can potentially be caused over the long run by increasing obsolescence, degradation of material quality over time, and market forces. The recoupment price for stockpiled material here is represented as the product of the future market price of the material, *FP*, and the sales recoupment fraction, *r*. The future price, *FP*, is estimated for each material as the long term (10 year) average real price.[15] The stockpile recoupment fraction, *r*, was evaluated by considering available historical data on stockpile sales. Based on DLA acquisition and sales data for beryllium, germanium, and tantalum-based materials, the relationship between the value of sales made by DLA and the value such a sale should have returned based on market prices was examined using regression (weighted least squares) analysis. The analysis showed that the historical recoupment fraction is approximately 84 percent. This estimate is somewhat uncertain because it is based on a relatively small fraction of total DLA sales (because of limited available data) but it has been used in estimating net stockpiling costs for each of the Base Case shortfall materials.

The discussion above explains how net cost is estimated for any given quantity of material to be stockpiled. As noted in the previous section discussing the effectiveness of stockpiling, stockpiling has a probability of success less than unity. On that basis, where stockpiling is determined to be needed to eliminate a shortfall, the quantity of material to be acquired for stockpiling is taken to be the amount needed to eliminate the shortfall divided by the stockpiling probability of success (see Appendix 11). Thus, to compare the cost-effectiveness of the mitigation measures in eliminating shortfall risk for each shortfall material, this discussion assumes that sufficient material will be stockpiled to completely eliminate the shortfall.

Net stockpiling costs for each Base Case shortfall material (in current dollars) reflecting the amounts necessary to completely eliminate shortfall risk (see Appendix 11) are set forth in the table below. Negative costs shown in parentheses are benefits (profits).

---

[15] In the presence of uncertainty, it is common practice to assume that material prices over a period of time will regress towards the mean long run price. Therefore, a model for the prevailing market price can be expected to resemble the average price over recent history.

Table 12-9. Estimated Net Present Costs of Stockpiling Sufficient Material to Eliminate Base Case Shortfall Risk

Material	Quantity	Units	Net Cost ($M)
Aluminum Oxide	302,215	ST	72.40
Antimony	30,105	ST	175.79
Beryllium	52	ST	0.00
Bismuth	4,760,342	LB	34.50
Chromium	867	ST	12.14
Dysprosium	64	MT	4.90
Erbium	177	MT	(96.44)
Fluorspar	73,379	ST	20.65
Gallium	23,049	KG	4.77
Germanium	37,196	KG	13.22
Manganese	9,842	ST	24.95
Scandium	772	KG	(8.82)
Silicon Carbide	107,645	ST	66.20
Tantalum	810,253	LB	21.54
Terbium	9	MT	(3.72)
Thulium	29	MT	(163.00)
Tin	26,533	MT	363.82
Tungsten	14,585,864	LB	30.39
Yttrium	2,658	MT	(425.51)

In some cases it is projected that net stockpiling costs would be negative, i.e., that the government would likely sell the material for more than its current acquisition price. That is caused by materials with current prices significantly below their longer term averages.[16] Such a result could occur with any material

[16] Rare earth mineral prices are currently at less than 40 percent of their 2011 peaks but still over five times higher than their prices in 2009. Biman Mukherji and Tom Wright, "India Bets on Rare-Earth Minerals," *The Wall Street Journal* (Aug. 14, 2012).

although it is more likely with materials that are exhibiting high price volatility. Whether the government would be able to mitigate shortfall risks for those materials by stockpiling at no net cost (or even a net benefit) will depend on whether prices for those materials at the time of acquisition remain low relative to longer-term averages.

Cost of Creating Buffer Inventories of Shortfall Materials

A policy alternative to creating a traditional stockpile is the creation of a buffer stock inventory, in which the government contracts with a third party to purchase, store and maintain a specified inventory of a material. In the event of a conflict, the government would purchase the material to meet requirements. The cost of maintaining a buffer stock will be dependent on the agreed upon details in the contract between the government and the third party, but past DLA practice suggests that annual buffer stock costs to the government would be approximately 15 percent of acquisition costs. Because the material is vendor owned and maintained, payments must be made annually. The price of the material in the event of a conflict can be negotiated to be roughly equivalent to the price the vendor paid at the time of acquisition. The cost of the government's potential acquisition of the material in the event of a conflict is weighted by the probability of the conflict, distributed uniformly across the planning period (five years).

Hence, the expected net cash flow associated with creating a buffer stock can be seen in Table 12-10, for each year over the planning period, where x = material amount, MP = market price, and p = probability of conflict sometime in the next five years.[17]

Table 12-10. Expected Net Cash Flow for Creating a Shortfall Buffer Inventory

Year Index	0	1	2	3	4
Expected Net Cash Flow	$0.15MPx + \frac{p}{5}MPx$	$0.15MPx + \frac{p}{5}MPx$	$0.15MPx + \frac{p}{5}MPx$	$0.15MPx + \frac{p}{5}MPx$	$0.15MPx + \frac{p}{5}MPx$

As noted above, the appropriate discount factor is applied to the net cash flow in each year in the calculation of NPV for this mitigation measure. The net costs of establishing and maintaining buffer inventories of each shortfall material over a five

[17] The total expected cost for the five year period is distributed evenly across each year of the planning period because the approach assumes that conflict is equally likely in each year.

year planning period and potentially purchasing the materials to mitigate shortfalls during the Base Case scenario are shown below (in current dollars).

Table 12-11. Estimated Net Present Costs of Buffer Inventories for Base Case Shortfalls

Material	Quantity	Units	Net Cost ($M)
Aluminum Oxide	231,485	ST	98.45
Antimony	22,575	ST	136.11
Beryllium	52	ST	12.05
Bismuth	3,629,659	LB	29.6
Chromium	718	ST	7.99
Dysprosium	47	MT	16.18
Erbium	124	MT	9.29
Fluorspar	56,322	ST	16.11
Gallium	17,686	KG	7.84
Germanium	28,888	KG	26.66
Manganese	7,406	ST	17.16
Scandium	572	KG	0.58
Silicon Carbide	81,869	ST	70.19
Tantalum	623,307	LB	31.46
Terbium	7	MT	5.35
Thulium	20	MT	2.48
Tin	19,428	MT	311.12
Tungsten	11,288,268	LB	63
Yttrium	1,899	MT	63.69

Cost of Increasing Imports of Materials (Extra Buys) during a Scenario

Traditional stockpiling and buffer stocks both require an expenditure of cash prior to a crisis or conflict. One other policy option, increasing material imports during the crisis or conflict, requires no cash expenditure before a scenario. That option assumes that during the emergency, the United States goes to key reliable foreign suppliers and contracts to buy a larger share of the additional material (at premium, wartime prices) that those suppliers are assumed to bring into production during the emergency.[18] The larger share initially estimated to be available is equal to the additional amount brought into production, minus the normal fraction of the material obtained by the United States during peacetime (which the United States is assumed to be able to obtain during the emergency as well), multiplied by a fraction, taken here to be 50 percent. Production levels and foreign production capacities for each shortfall material were taken from the data used in the shortfall calculations. See Appendix 7 for further explanation. The cost of the material is taken to be simply the projected market price of the material purchased during the emergency.

As seen in Table 12-12, there is no expenditure prior to a scenario for increasing imports. The only potential cash flow is the necessary acquisition of the extra material once a conflict has begun. This option assumes that the United States goes into the market to acquire a higher fraction than normal of the world's production of each of the shortfall materials under crisis market conditions. We assume that such efforts would require more purchasing power than could be mustered by individual consumers and thus, that the U.S. government would buy the extra material. Therefore, the costs for this option to the government are the expected acquisition costs of the quantity of each material purchased. Where increasing imports is found to be partially effective such that less than the needed quantities described above would be available for purchase during the scenario (see Appendix 11), the net present cost of this option is estimated based on the actual quantity that is estimated to be available.

While assuming U.S. government purchases to cover civilian shortfalls might seem to be unduly conservative, it could also be seen as analogous to stockpiling, where the government also purchases material to cover civilian shortfalls, albeit before the crisis occurs. In both cases, the government may in turn sell the material to civilian consumers and recoup some or all of its acquisition costs. However, because of the speculation that would be required to assess those processes we do not treat potential sale to consumers during the scenario for stockpiling or for increased imports.

The market price of a material in the event of a conflict may be significantly higher than the current market price. Hence, this acquisition is calculated using the estimated market price of a material in conflict and is weighted by the probability of conflict, distributed uniformly across the planning period (in this case, five years).

[18] For all shortfall materials it is assumed that suppliers will bring any existing but idle capacity up to full production six months into the scenario. Thus, for the latter six months of the first year of the scenario (and beyond) there will be additional material brought into the market beyond that available before the emergency. This option posits the United States buying some fraction of that additional material.

In Table 12-12, for each year over the planning period, x = material amount, MP_{max} is the market price of a material in the event of a conflict and p = probability of conflict sometime in the next five years. As noted, the appropriate discount factor is applied to the net cash flow in each year in the calculation of NPV for this mitigation measure.

Table 12-12. Expected Net Cash Flow for Increased Imports (Extra Buys)

Year Index	0	1	2	3	4
Expected Net Cash Flow	$+\frac{p}{5}MP_{max}x$	$+\frac{p}{5}MP_{max}x$	$+\frac{p}{5}MP_{max}x$	$+\frac{p}{5}MP_{max}x$	$+\frac{p}{5}MP_{max}x$

The market price of a material during a conflict or other emergency will vary based on source of supply, type of disruption scenario, fungibility in the market and other variables. Historical prices for each material were examined for peaks relative to the recent past that could represent the kind of price increase that could result from supply and/or demand shocks that could occur during a conflict or other serious supply disruption. Annual average prices from 1900 to the present for each material were compared to annual average prices from one to five years before each year considered. The maximum relative difference over the data period, between each peak and the price one to five years prior, was taken to be the magnitude of the price increase for each material that might be produced by a conflict.[19] Examination of this statistic is common in finance when assessing price volatility. Price changes over one, two, three, four, and five year increments were included to cover the potential for prices to adjust over a period longer than one year as firms sense the imminence of conflict or other crisis. A maximum price increase calculated using only one year time increments could understate this effect. These estimates of potential price increases are necessarily imprecise because of the multiple supply- and demand-related conditions and factors that would govern price increases during a real future emergency. Nevertheless, the potential quantities of each shortfall material available by increasing imports, the maximum price multiples for each material (relative to prevailing long run prices), and the resulting estimated net costs are set forth in the table below.

[19] For some materials prices are not generally reported for the exact form of material considered (e.g., aluminum oxide and silicon carbide). For those materials, the contained metals are used as proxies for estimating long run average prices and the maximum change in material prices. For long run prices, the ratio of current shortfall material price and current proxy material price is multiplied by the long run average proxy material price to estimate a long run average price for the shortfall material. The use of these proxies is a reasonable approximation because of the direct relationship between the production of the proxy and the production of the shortfall material. That likely causes the price movements of the two materials to mirror each other closely.

Table 12-13. Estimated Price Multiples and Net Present Costs of Increased Imports (Extra Buys) Available to Cover Base Case Shortfalls

Material	Quantity	Units	Price Multiple	Net Cost ($M)
Aluminum Oxide	18,562	ST	3.00	0.114
Antimony	4,321	ST	3.92	0.234
Beryllium	0	ST	1.99	0
Bismuth	983,537	LB	4.35	0.097
Chromium	0	ST	3.35	0
Dysprosium	0	MT	12.24	0
Erbium	0	MT	1.83	0
Fluorspar	56,322	ST	2.73	0.097
Gallium	2,656	KG	1.75	0.011
Germanium	4,649	KG	3.35	0.085
Manganese	7,406	ST	3.40	0.088
Scandium	0	KG	8.26	0
Silicon Carbide	13,599	ST	1.81	0.081
Tantalum	0	LB	7.20	0
Terbium	0	MT	5.43	0
Thulium	0	MT	2.67	0
Tin	17,208	MT	2.43	1.999
Tungsten	4,299,459	LB	4.77	0.686
Yttrium	63	MT	2.12	0.170

The low net costs associated with increased imports for each shortfall material available are driven by the low probability of the scenario and hence the low probability that these costs would ever be incurred, even given the assumption of wartime price increases.

Cost of Not Guaranteeing Materials to Produce Exported Goods during a Scenario

The fourth shortfall mitigation option under consideration is for the government not to guarantee the supply of the designated fraction of shortfall materials that would normally be contained in exported goods. This option would have no monetary cost to the government.[20] The amount by which each shortfall could be reduced through not guaranteeing materials for exports of goods is set forth in Appendix 11.

[20] If limits on exports were actually imposed, market and trade disrupting effects could result in monetary costs to U.S. manufacturers and possibly importers.

Cost of Using Material Substitutes during a Scenario

The last shortfall mitigation option under consideration is turning to the use of substitute materials in lieu of shortfall materials or the use of other goods not containing shortfall materials (that could perform the same functions as goods containing shortfall materials) in lieu of goods containing shortfall materials. The potential use of substitutes to mitigate shortfalls is discussed in Appendix 9, *Substitution*. There it is explained that the use of substitutes in lieu of shortfall materials for civilian applications would impose no costs on the government (although using substitutes could impose costs on civilian consumers). Therefore, substitutes are considered to impose no costs in this shortfall mitigation risk and cost assessment.

Choosing Risk Mitigation Measures across Shortfall Materials

The last step in the process after the costs of mitigation measures have been evaluated is to select the measure(s) to apply to each material suffering a potential shortfall.[21] As noted above, the approach is to mitigate residual strategic materials risk on a material by material basis by applying a common risk threshold (or maximum risk) to all the materials and choosing a shortfall mitigation measure (or measures) for each material that would reduce risk for each material to the specified level. The risk threshold applied by DoD is based on consideration of the specific risks from material shortfalls (probabilities and consequences) identified during the analytical process. The specific mitigation measure chosen for each material is the one (or ones) that reduce risk to the specified threshold at the lowest net present cost. This approach allows DoD to make cost-risk tradeoffs by adjusting the threshold applied across the materials: as the risk threshold is raised, more mitigation options become available, which creates more opportunities to reduce risk to the required level at lower cost. This approach is illustrated below using two examples:

[21] If a mitigation measure is cost-effective but lacks the capacity to mitigate the entire shortfall, additional mitigation measures are potentially brought to bear on the shortfall to reduce its risk to an acceptable level.

Table 12-14. Considering Risk Mitigation Across Shortfall Materials

Material:	**Aluminum Oxide**		
Shortfall Risk	**Mitigation Measure**	**Residual Risk**	**Mitigation Cost ($M)**
0.043	Extra Buy	0.040	0.11
0.043	Substitution	0.003	0
0.043	Reduced Exports	0.038	0
0.043	Stockpiling	0.000	72.40
Material:	**Chromium Metal**		
Shortfall Risk	**Mitigation Measure**	**Residual Risk**	**Mitigation Cost ($M)**
0.015	Extra Buy	0.015	0.00
0.015	Substitution	0.000	0
0.015	Reduced Exports	0.000	0
0.015	Stockpiling	0.000	12.14

This example shows a pattern evident with both materials and with the others evaluated in this report. For both aluminum oxide and chromium, there are two options—substitution and reduced exports—that impose no cost on the government. For aluminum oxide, extra buy (increased imports) is available and less expensive on a net present basis than stockpiling (in absolute terms as well as relative to its risk mitigating capacity), but for chromium it is not available. These results suggest that substitution and reduced exports should be considered for mitigating the risk from these shortfalls first, followed by extra buy (for aluminum oxide), then stockpiling.

If multiple options are considered, they can be applied in that order as well. The extent to which the measures with costs—extra buy and stockpiling—are needed for these materials depends on the extent to which DoD can accept the shortfall risk remaining after the measures without costs are applied. Following the equation for the calculation of residual shortfall risk after the application of one shortfall mitigation measure, the risk remaining of the application of subsequent measures is proportional to the expected shortfall remaining after the application of each measure. In the case of aluminum oxide, substitution, reduced exports, and extra buy, together would not be sufficient to eliminate the risk, so if the residual risk after extra buy was applied was still deemed to be too high, stockpiling could be used to reduce the risk to an acceptable level. In the case of chromium, substitution and reduced exports together would be sufficient to eliminate the expected risk,[22] so stockpiling would appear to be unnecessary. Nevertheless, notwithstanding the results of this quantitative analysis, DoD may still deem it prudent to implement additional material shortfall risk mitigation measures to hedge against uncertainties or risks not yet fully analyzed.

This cost-effectiveness approach is applied to the analysis of all of the shortfall materials in the Base Case in the following table. For each material in shortfall, each of the four mitigation measures is evaluated for risk reduction and net present cost is estimated as explained above.

Table 12-15. Risk Mitigation Measures and Costs for Base Case Shortfall Materials

Material:	**Aluminum Oxide**		
Shortfall Risk	**Mitigation Measure**	**Residual Risk**	**Mitigation Cost ($M)**
0.043	Extra Buy	0.040	0.11
0.043	Substitution	0.003	0
0.043	Reduced Exports	0.038	0
0.043	Stockpiling	0.000	72.40
Material:	**Antimony**		
Shortfall Risk	**Mitigation Measure**	**Residual Risk**	**Mitigation Cost ($M)**
0.041	Extra Buy	0.033	0.23
0.041	Substitution	0.034	0
0.041	Reduced Exports	0.037	0
0.041	Stockpiling	0.000	175.79
Material:	**Bismuth**		
Shortfall Risk	**Mitigation Measure**	**Residual Risk**	**Mitigation Cost ($M)**
0.040	Extra Buy	0.029	0.10
0.040	Substitution	0.039	0
0.040	Reduced Exports	0.034	0
0.040	Stockpiling	0.000	34.50
Material:	**Chromium Metal**		
Shortfall Risk	**Mitigation Measure**	**Residual Risk**	**Mitigation Cost ($M)**
0.015	Extra Buy	0.015	0.00
0.015	Substitution	0.000	0
0.015	Reduced Exports	0.000	0

[22] Because of the probabilistic nature of this problem and the uncertainties associated with all of the quantities used to estimate shortfalls and shortfall risk, true risk can never be entirely eliminated.

0.015	Stockpiling	0.000	12.14

Table 12-15. Risk Mitigation Measures and Costs for Base Case Shortfall Materials (continued)

Material:	**Dysprosium**		
Shortfall Risk	**Mitigation Measure**	**Residual Risk**	**Mitigation Cost ($M)**
0.025	Extra Buy	0.025	0.00
0.025	Substitution	0.021	0
0.025	Reduced Exports	0.016	0
0.025	Stockpiling	0.000	4.90
Material:	**Erbium**		
Shortfall Risk	**Mitigation Measure**	**Residual Risk**	**Mitigation Cost ($M)**
0.047	Extra Buy	0.047	0.00
0.047	Substitution	0.041	0
0.047	Reduced Exports	0.042	0
0.047	Stockpiling	0.000	(96.44)
Material:	**Fluorspar**		
Shortfall Risk	**Mitigation Measure**	**Residual Risk**	**Mitigation Cost ($M)**
0.012	Extra Buy	0.000	0.10
0.012	Substitution	0.000	0
0.012	Reduced Exports	0.000	0
0.012	Stockpiling	0.000	20.65
Material:	**Gallium**		
Shortfall Risk	**Mitigation Measure**	**Residual Risk**	**Mitigation Cost ($M)**
0.040	Extra Buy	0.034	0.01
0.040	Substitution	0.027	0
0.040	Reduced Exports	0.028	0
0.040	Stockpiling	0.000	4.77
Material:	**Germanium**		
Shortfall Risk	**Mitigation Measure**	**Residual Risk**	**Mitigation Cost ($M)**
0.044	Extra Buy	0.037	0.09
0.044	Substitution	0.037	0
0.044	Reduced Exports	0.038	0
0.044	Stockpiling	0.000	13.22

Table 12-15. Risk Mitigation Measures and Costs for Base Case Shortfall Materials (continued)

Material:	**Manganese Metal**		
Shortfall Risk	**Mitigation Measure**	**Residual Risk**	**Mitigation Cost ($M)**
0.025	Extra Buy	0.000	0.09
0.025	Substitution	0.025	0
0.025	Reduced Exports	0.019	0
0.025	Stockpiling	0.000	24.95
Material:	**Scandium**		
Shortfall Risk	**Mitigation Measure**	**Residual Risk**	**Mitigation Cost ($M)**
0.026	Extra Buy	0.026	0.00
0.026	Substitution	0.001	0
0.026	Reduced Exports	0.025	0
0.026	Stockpiling	0.000	(8.82)
Material:	**Silicon Carbide**		
Shortfall Risk	**Mitigation Measure**	**Residual Risk**	**Mitigation Cost ($M)**
0.029	Extra Buy	0.024	0.08
0.029	Substitution	0.014	0
0.029	Reduced Exports	0.023	0
0.029	Stockpiling	0.000	66.20
Material:	**Tantalum**		
Shortfall Risk	**Mitigation Measure**	**Residual Risk**	**Mitigation Cost ($M)**
0.030	Extra Buy	0.030	0.00
0.030	Substitution	0.030	0
0.030	Reduced Exports	0.014	0
0.030	Stockpiling	0.000	21.54
Material:	**Terbium**		
Shortfall Risk	**Mitigation Measure**	**Residual Risk**	**Mitigation Cost ($M)**
0.022	Extra Buy	0.022	0.00
0.022	Substitution	0.004	0
0.022	Reduced Exports	0.007	0
0.022	Stockpiling	0.000	(3.72)

Table 12-15. Risk Mitigation Measures and Costs for Base Case Shortfall Materials (concluded)

Material:	**Thulium**		
Shortfall Risk	**Mitigation Measure**	**Residual Risk**	**Mitigation Cost ($M)**
0.040	Extra Buy	0.040	0.00
0.040	Substitution	0.026	0
0.040	Reduced Exports	0.035	0
0.040	Stockpiling	0.000	(163.00)
Material:	**Tin**		
Shortfall Risk	**Mitigation Measure**	**Residual Risk**	**Mitigation Cost ($M)**
0.029	Extra Buy	0.003	2.00
0.029	Substitution	0.024	0
0.029	Reduced Exports	0.019	0
0.029	Stockpiling	0.000	363.82
Material:	**Tungsten**		
Shortfall Risk	**Mitigation Measure**	**Residual Risk**	**Mitigation Cost ($M)**
0.034	Extra Buy	0.021	0.69
0.034	Substitution	0.029	0
0.034	Reduced Exports	0.028	0
0.034	Stockpiling	0.000	30.39
Material:	**Yttrium**		
Shortfall Risk	**Mitigation Measure**	**Residual Risk**	**Mitigation Cost ($M)**
0.050	Extra Buy	0.048	0.17
0.050	Substitution	0.044	0
0.050	Reduced Exports	0.045	0
0.050	Stockpiling	0.000	(425.51)

The Base Case shortfall materials show the same pattern evident for the example discussed above. For all of the shortfalls there are two risk mitigation options—substitution and reduced exports—that impose no cost on the government. For most shortfalls, the third option, extra buy (increased imports), is available and less expensive on a net present cost basis than the fourth option, stockpiling (in absolute terms as well as relative to its risk mitigating capacity). These results, by themselves, would suggest that substitution and reduced exports should be considered for mitigating the risk from all shortfalls first, followed by extra buy (for the materials for which it is available), then stockpiling. However, as noted at the beginning of the report, in light of the relatively low costs of extra material buys and policy considerations in favor of not requiring the use of substitutes or potentially disrupting U.S. exports, this report recommends implementing extra buys first, followed by substitution, followed by reduced exports, and then stockpiling.

There are a small number of cases where the estimated net present cost of stockpiling is negative, i.e., it is currently estimated that upon selling the stockpile the government would ultimately recoup more than the acquisition cost of the material in question. In those instances if prices for those materials remain low relative to longer-term averages, stockpiling could be more cost effective than the other shortfall risk mitigation measures.

Where multiple options are considered, they can be applied in the order suggested above as well. The extent to which each successive measure is needed for each material depends on the extent to which DoD can accept the shortfall risk remaining after the preceding measures are applied. This approach is shown in Figure 4 of the main report in which these mitigation measures are applied as needed to eliminate each of the expected shortfalls and hence eliminate expected shortfall risk.[23] The table shows the extent to which each of the successively applied mitigation measures is needed to eliminate each shortfall and the resulting amount of material needed to be stockpiled to do so. Nevertheless, as noted above, DoD may still deem it prudent to implement additional material shortfall risk mitigation measures to hedge against uncertainties or risks not yet fully analyzed.

[23] Because of the uncertainties associated with all of the quantities used to estimate shortfalls and shortfall risk, all risk from potential material shortfalls can never be entirely eliminated.

Appendix 12 Annex
Strategic Risk Assessment

To support risk assessments associated with specific strategic material shortfalls, the Department of Defense (DoD) conducted a complementary, overarching risk assessment focused on broader strategic risks to U.S. national interests. This exercise consisted principally of structured interviews with senior retired and currently serving national security professionals, both military and civilian. Participants in these interviews provided risk scores for future scenarios and categories of operations, and in doing so, offered quantitative estimates of both the probabilities and consequences associated with those scenarios and operations. In addition to the quantitative estimates for consequences (expressed as negative political, military, and economic utilities in each respondent's value system), respondents were asked to defend their estimates by providing supporting rationale. Participants in this exercise are shown in Table 12A-1.

Table 12A-1: Strategic Risk Assessment Exercise Participants

Name	Senior Government Positions (now retired from government, except as noted)
Matthew Beebe	Deputy Director, Acquisition, Defense Logistics Agency (current)
Frank Carlucci	Secretary of Defense, National Security Advisor to the President
George Casey	Chief of Staff, U.S. Army
Kevin Chilton	Commander, U.S. Strategic Command
David Chu	Undersecretary of Defense (Personnel and Readiness)
Vernon Clark	Chief of Naval Operations
Michael Dominguez	Acting Secretary of the Air Force, Principal Deputy Undersecretary of Defense (Personnel and Readiness)
Alan Estevez	Assistant Secretary of Defense (Logistics and Materiel Readiness) (current)
Carlton Fulford	Deputy Commander, U.S. European Command
Albert Gray	Commandant, U.S. Marine Corps
Michael Hayden	Director, Central Intelligence Agency
H.T. Johnson	Acting Secretary of the Navy, Commander, U.S. Transportation Command
Robert Manning	Deputy National Intelligence Officer, Economic Issues (current)
Deborah McWhinney	Chief Operating Officer, Citi Global Enterprise Payments, Citigroup (current – non-government)
Richard Porterfield	Director for Intelligence, U.S. Pacific Command
Philip Rodgers	Deputy Director, Acquisition Resources Analysis, Office of the Secretary of Defense (current)
Larry Welch	Chief of Staff, U.S. Air Force
John White	Deputy Secretary of Defense

Information developed from this strategic risk assessment exercise supported the more detailed and specific strategic materials risk assessments in two ways:

- It provided subject matter expert (SME)-estimated probabilities for selected conflict scenarios that could cause strategic material shortfalls; these probabilities were used in calculating the risk associated with those shortfalls. It also provided estimated probabilities for the Base Case scenario used in this report. Those probabilities are shown in Table 12A-2 (with Base Case scenario probabilities listed as "Future #1" and "Future #2").[1]

[1] Association of specific scenarios with the Base Case is classified and can be found in the classified appendix of this report.

Table 12A-2: Selected Scenario Probabilities

	Probability		
	Max	Mean	Min
China	11%	4%	0%
Iran	60%	19%	6%
North Korea	18%	8%	0%
Homeland Nuclear Attack	30%	6%	0%
Future #1	2%	0.8%	0%
Future #2	5%	0.9%	0%

- Descriptions from the strategic interviews of adverse scenario consequences to U.S. economic, military, and political interests were summarized and provided to strategic material SMEs to add context to their own estimates of the adverse consequences of material shortfalls. The summary descriptions are shown below.

China

- Gross domestic product (GDP) losses would be high, and the consequences would extend over a significant timeframe. The negative economic consequences would be on both sides, too. In the United States, you might see hyperinflation because of the scarcity of consumer goods, and the Chinese might dump their U.S. debt, putting further pressure on the dollar. Our U.S. allies would be more likely to stick with the United States than to defect, which limits the political consequences, but defections are possible.
- Economic consequences of war with China are high based on the mutual dependence between the two countries. Militarily the conflict would be violent, but quick; and we would get the better of it, at least in the next ten years. Politically, there would be some loss of credibility on both sides, due to the failure to prevent the war. Trade disruptions would also have major Chinese domestic political consequences.
- A South China Sea conflict could start over our coming to the assistance of one or more Association of Southeast Asian Nations allies. The economic consequences here would be significant based on a major disruption of world trade.

Iran

- In contrast with China, Iran has less to lose from disrupting global trade and economic relations. So their willingness to challenge the status quo and to escalate the conflict is significant. They could attack Gulf countries, harass shipping in the Strait, or even attack the United States through Hezbollah or Quds Force.

- A conflict with Iran is likely to escalate significantly. It would involve Israel, possibly involve the North Atlantic Treaty Organization, and would turn into an extended conflict. Oil disruptions would cause significant economic consequences.
- There is risk associated with escalation—Iran could pursue unconventional military options to retaliate such as firing missiles at Israel, at the Golf Corporation Council countries, at our forces in the region, as well as engaging in covert special operations or terrorist attacks against U.S. interests.
- Consequences of a war with Iran would be much more economic and political than military. We will neutralize their military fairly quickly. In markets, however, fear creates its own economic consequences, maybe even more than direct damage.
- For a Strait of Hormuz scenario, the most significant consequences are economic, based on the impact to world trade. Military consequences would be small, assuming that we will respond quickly.

North Korea

- The North Korean regime will eventually collapse followed by significant instability and violence. Parts of the military might try to fight any external parties attempting to intervene. This could be a large operation, requiring lots of people and some conventional combat, plus involving North Korean use of chemical weapons.
- In Korea, government collapse is much more likely than the classic invasion scenario. Consequences would not be severe, even though it might be very difficult and time consuming to secure the regime's nuclear weapons. China could get involved in the collapse scenario, but there are many incentives for them to cooperate with us.
- A Korean conflict would disrupt the South Korean economy, but other Asian countries could absorb and offset the resulting impact to some degree.
- The consequences depend on whether China gets involved. China's staying out and/or playing a productive role is more likely than not, and it would be significantly less consequential than if they do become militarily confrontational.

Homeland Nuclear Attack

- Nuclear and radiological attacks both have very high consequences. Even a radiological bomb, dispersed in Manhattan, would take thousands of years to clean up. The location and extent of the weapon's effects would drive the size and character of economic and political consequences.

- There are a lot of Weapons of Mass Destruction (WMD) materials out there and plenty of will and intent to use them. Physical and monetary losses are not the only matters of consequence in a WMD attack; the psychological effects of WMD are significant. A WMD attack would leave a "dead zone" that would suppress economic activity for a very long time. In prominent places, like Manhattan or Washington, or ports in New York or Los Angeles, WMD effects are more pronounced and would have serious effects for a very long time.
- In a nuclear attack, economic consequences will be the greatest, though the military will still be affected to some degree, since it has significant assets near population centers.

Exercise Method

The framework used for the strategic risk assessment was drawn from the Integrated Risk Assessment and Management Model (IRAMM),[2] which was developed in 2004 and 2005 to support an expert elicitation exercise involving senior military and civilian leaders in DoD. This framework consisted of one-on-one, not-for-attribution interviews with senior leaders that lasted approximately 1.5 hours on average. Participants were asked to identify the strategic risk to the United States that they perceived in the decade from 2012 to 2021, based on their expectations for the performance of the currently-programmed portfolio of U.S. military forces.

The exercise was structured in the following way. First, four "challenge areas" were defined that together cover a full range of potential operations conducted by the U.S. military. The challenge areas and their definitions used in this exercise are shown in Figure 12A-1.

[2] The name IRAMM was adopted in 2009. Before this, the framework described here was known as ICCARM (Integrated Cross-Capability Assessment and Risk Management).

Figure 12A-1: Challenge Areas

Challenge Areas	Definitions
Major Combat	Operations conducted against a state or non-state actor that possesses significant military capability. This area should account for risk related to the use of WMD during the course of major combat. *e.g., China, North Korea, Iran, Libya*
Irregular Warfare	Stability operations, counterinsurgency, peacekeeping, or counterterrorism operations involving significant participation of U.S. forces in combat or prospective combat. *e.g., Iraq, Afghanistan, Bosnia, Somalia*
Homeland Defense	Protection of U.S. sovereignty, territory, population, and critical infrastructure against external threats. This area should delineate among risks from WMD, cyber attack, and all other forms of external attack (except those directly related to Major Combat). *e.g., 9/11, missile attack, WMD attack, cyber attack, other terrorist attack*
Global Peacetime Operations	Operations conducted to influence partners and adversaries. This area should account for risks related to changes in allied or adversary military capabilities, weapons proliferation, or political instability that are contrary to U.S. peacetime military objectives but do not result in U.S. combat operations. *e.g., presence, deterrence, building partnership capacity, counter-proliferation, freedom of navigation, humanitarian and disaster response.*

Respondents were asked to estimate risk for each of the four challenge areas based on their own identification of one or more scenarios in each of the challenge areas. For each scenario that the respondents identified, they were asked to estimate: 1) the likelihood that the scenario occurs in the next 10 years; and 2) the consequences of the scenario given that it occurs using the IRAMM consequence scale. These two parameters were then generally combined by multiplication, thus generating a risk score on a scale of zero to one hundred. This risk score is interpreted as the "expected value of loss" over the ten year period. For scenarios that were ongoing (e.g., stability operations in Afghanistan), respondents were asked simply to provide an estimate of consequences for the duration of those scenarios or conditions using the consequence scale; this estimate was considered to be the expected value of loss (as described below) since the probability for a scenario already occurring is 1.0 and has no effect on consequences.

The IRAMM consequence scale (see Figure 12A-2) is akin to multi-attribute utility scales. The attributes are economic, military, and political consequences. The consequence scale is defined largely by descriptions of these attributes, which were based in part on the findings from a 2000 study co-chaired by General Andrew Goodpaster.[3]

[3] The Commission on America's National Interests, *America's National Interests* (Cambridge, MA: Belfer Center for Science and International Affairs, July 2000).

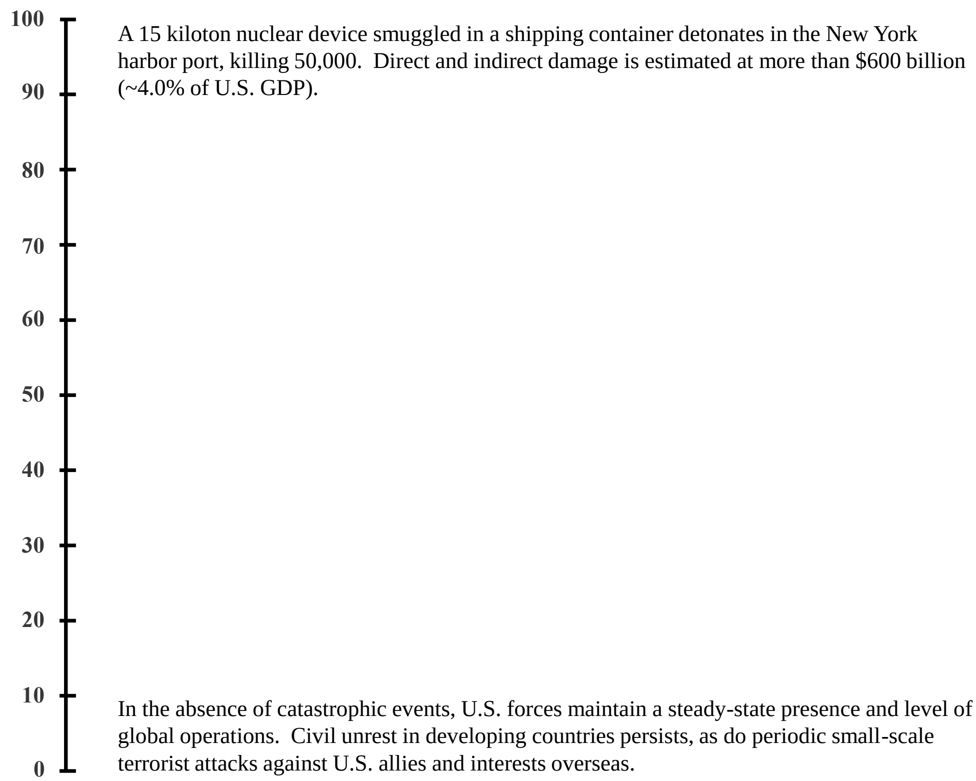
That study presented a hierarchy of U.S. strategic interests in each of these three categories with the highest category defined as "vital" (threatening the survival of the United States as a sovereign nation), and lesser categories defined in terms of decreasing importance. The criteria for each category identified in that report were refined to the bullet form that appears in the IRAMM consequence scale.

Figure 12A-2: Consequence Scale

Economic	Military	Political	
• 4% or greater cumulative loss in GDP • Extreme, semi-permanent structural and economic costs. • Capital flows massively degraded and/or dollar collapses jeopardizing U.S. economic foundation. • Alliances and economic agreements terminated.	• Loss of more than 10% of overall military force capability; recovery longer than 4 years. • Covering worldwide mission areas adequately is impossible. • Deterrence severely compromised in key areas. • Potential international condemnation due to high non-combatant casualties. • Loss of confidence in military, internally and externally.	• The U.S. seen as unreliable by multiple allies or coalition partners and new regional security orders emerge. • Loss of credibility as guarantor of global security. • Allies and friends create their own nuclear arsenals to guarantee their security • Competitors become increasingly aggressive and adversarial.	Most Severe
• 3% cumulative loss in GDP • Severe economic costs resulting from trade disruptions, operational factors, or property damage. • Capital flows seriously degraded and/or substantial devaluation of dollar. • Global economy stalled. • Recovery eventually.	• Loss of 5-10% of overall military force capability; recovery within 4 yrs • Reduced worldwide mission areas commitment. • Deterrence weak in key areas. • Critical U.S. vulnerability revealed to all from military surprise. • International criticism due to high non-combatant casualties.	• U.S. strategic influence severely degraded. • U.S. loses credibility in one or more key regions of the world. • One or more competitors takes advantage of perceived U.S. weakness. • Some coalitions fail; some allies turn away from the U.S.	
• 2% cumulative loss in GDP • Serious economic costs due to trade disruptions, operational factors, or property damage. • Capital flows degraded and /or value of dollar weakens. • Economic disruptions possible, but no recession follows. • Reconstruction of key economic capabilities could take months.	• Loss of 1-5% of military force capability; recovery within 18 months. • Worldwide mission areas still covered. • Overall mission success not questioned. • Deterrence weaker, but still strong. • High non-combatant casualties.	• U.S. weakened as major global political broker. • International cooperation with U.S. put at risk. • U.S. credibility weakened with one or more competitors. • U.S. partners doubt U.S. commitment and begin to forge separate security arrangements or seek unilateral measures to guarantee their security.	
• 1% cumulative loss in GDP • Some economic costs due to trade disruptions, operational factors, or property damage. • Confidence quickly restored domestically and internationally.	• Loss of less than 1% of military force capability.. • Worldwide mission areas covered adequately. • Low or predicted non-combatant casualties.	• Some political opposition to and suspicion of U.S. intentions in previously friendly countries. • Reduced willingness of allies and friends to cooperate with U.S. on other international security goals.	
• Negligible effect on GDP	• No major loss of military force capability overall. • Worldwide mission areas covered adequately. • Low or predicted non-combatant casualties.	• Some minor political opposition to and suspicion of U.S. intentions in previously friendly countries.	Least Severe

The final step in constructing the consequence scale was to define short scenario descriptions that would serve as calibration points for the top and the bottom of the 100-point scale (see Figure 12A-3). A scenario involving a nuclear attack on the U.S. homeland was given a value of 100, which represented its combined political, military, and economic consequences should it occur. Another scenario depicting no significant military events over the 2012-2021 decade was associated with the bottom of the scale, representing a consequence score close to zero on the 100-point scale. Respondents were asked to estimate their consequence scores for the scenarios they identified in relation to these calibration points. Respondents deemed almost all of the scenarios they identified to be less consequential than the 100-point calibration scenarios, and the combined utility (a combination of political, military and economic consequences) was estimated as a percentage or fraction of the calibration scenarios. In practice, nothing prohibited respondents from estimating consequences that were greater than the 100 assigned to the calibration scenarios.

Figure 12A-3: Consequence Scale Calibration Scenarios



Respondents used the scales in the following way. For each scenario, they identified within a given challenge area, they were asked to provide the probability that the scenario would occur in the next decade, and then the political, military and economic consequences of the scenario using the criteria provided in the cells of the scale and the calibration scenarios. For discrete events such as major combat operations, the elicitation technique used event tree constructions with mutually exclusive terminal nodes that expressed the "expected value" calculations of risk—in essence the expected value of the utility estimated using the consequence scale.

This expected value was produced in accordance with each respondent's own value system. That is, for each scenario in the challenge area, respondents were asked to estimate political, military and economic consequences separately and then combine them. The method of combination was left to their discretion, although most chose to average the consequences. Note that in the construction of the consequence scale, the criteria noted in each column (economic, military, political) were considered roughly equal based on the horizontal alignment of their associated cells. Since there were five cells aligned vertically in each consequence column, respondents tended to assign utilities in five equal-sized bins, from 0–20, 20–40, 40–60, 60–80, and 80–100. However, respondents were not bound to this assignment of utility and were left free to assign utility values in accordance with their value system on a scale of 0 to 100+. The criteria in the cells were also used to provide talking points that were scaled in accordance with the ranking of the cells in each consequence category; that is, the criteria described increasingly severe consequences from the bottom of the scale to the top in each category.

Throughout the elicitation process, respondents were asked to provide pairwise comparisons between new consequence estimates and previous estimates and to ensure that the ratios for each comparison were consistent with their judgments about those risks. For example, a respondent who had estimated a consequence score of 40 would be asked to verify that this consequence level was twice as consequential as a consequence of 20 that he/she had made previously.

As noted above, risk scores were generated for scenarios involving discrete events by combining consequence estimates with probability estimates for the events—initially by forming a product of the two values. Since all three metrics—risk, probability and consequences—serve the purpose of providing quantitative decision metrics used to compare the overall hypothetical performance of a given force structure from the perspective of managing strategic risk to the nation, the values of these decision metrics are formed in accordance with the value system of the individual respondents. Hence their use, quality, and effectiveness depend greatly on the experience, knowledge, and history of the respondents.

Appendix 13
Additional Cases Studied

Introduction

For the 2013 National Defense Stockpile (NDS) Requirements Study, a number of cases were examined in addition to the Base Case.

- One of these is considered of such key importance that it has been called the alternative base case. This case has been discussed at some length in the main report. This appendix supplements that discussion by presenting some additional material-by-material results for the case.
- A second set of additional cases concerns peacetime supply disruption scenarios, where supply from a given country suddenly becomes unavailable. These cases were mentioned in the main report; this appendix presents detailed results for them.
- A third set of additional cases are referred to as sensitivity cases: they vary some of the particular supply and demand assumptions of the Base Case. Analysis of how the material shortfall amounts vary with different changes in these assumptions can shed light on which supply- and demand-related factors are especially important, and can help identify possible shortfall mitigation options.

The three sections of Appendix 13 discuss these three sets of additional cases, in turn.

The cases discussed in this appendix all involve variations to the *inputs* to the Stockpile Sizing Module (SSM), and their effects on the shortfalls computed. It is also possible to explore variations in the success probabilities and mitigation amounts that are uses to develop mitigation strategies *from* the SSM results (Appendix 11). For example, the estimates of the success probabilities are subject to uncertainty. The results of some of these variations can be made available upon request.

Alternative Base Case

Assumptions

As noted in the main report, in the Base Case, available material supply from a foreign country (after all relevant supply decrements have been taken into account) is assumed to be able to satisfy defense and emergency investment demands unless the country provides 50 percent or more of the world supply of the material in question (the term “dominator” is sometimes used for such a country).[1] The alternative base case assumes that only supply from the United States and Canada can offset defense and emergency investment demands: supply from other countries can satisfy civilian demand only. The law requires analyzing a more stressful case than the Base Case; the alternative base case is one such case.

Results

As noted in the main report, for the 72 non-proprietary materials, 25 of them have shortfalls in the alternative base case, as opposed to 18 in the Base Case. The total value of their shortfalls is $2.7 billion, as opposed to $1.2 billion in the Base Case.[2] Eleven of the materials have defense shortfalls, and these persist throughout the whole scenario. The most striking shortfall is for natural rubber, which has a shortfall of $1.2 billion, by far the major portion of the incremental shortfall in the alternative base case. This is consistent with the alternative base case assumptions: the United States and Canada do not produce natural rubber, so all the defense and emergency investment demand becomes a shortfall.

The overall shortfalls in the alternative base case are as follows:

- Defense sector—11 materials have shortfalls, totaling $1.4 billion.
- Emergency investment sector—11 materials have shortfalls, totaling $56.9 million.
- Civilian sector—17 materials have shortfalls, totaling $1. 2 billion.

Three materials—bismuth, gallium, and tantalum—have shortfalls in all three sectors of demand. (Recall that the Base Case shortfalls are all in the civilian sector.)

Table 13-1 shows the results of the alternative base case and compares them with the Base Case shortfalls (materials not listed in Table 13-1 have shortfalls in neither case). Paradoxically, some of the civilian sector shortfalls are smaller in the alternative base case than in the Base Case. This is because material precluded from offsetting defense demands can be used to satisfy civilian demands.

---

[1] See the first part of Appendix 7 for definitions of the defense, emergency investment, and civilian sectors of demand.

[2] The shortfall numbers and dollar values reported in this appendix do *not* include the extrinsically specified stockpile goal of 52 short tons of beryllium metal, valued at about $16.1 million. The supply-demand comparison found a shortfall for beryllium metal in neither the Base Case nor the alternative base case.

Table 13-1. Alternative Base Case Shortfalls

Alternative Base Case -- Shortfall by sector of demand (units)							Base Case Shortfall	
Material	Units	Defense	Emergency Investment	Civilian	Total	Total $M Value	in Units	in $M
Aluminum Oxide Fused Crude	short tons	0	0	231,485	231,485	131.67	231,485	131.67
Antimony	short tons	0	0	22,575	22,575	182.04	22,575	182.04
Bauxite Metal Grade Jamaica & Suriname	short tons	1,438,063	68,688	0	1,506,751	40.90	0	0.00
Bismuth	pounds	20,104	81,338	3,528,217	3,629,659	39.59	3,629,659	39.59
Chromium Ferro (Ferrochromium)	short tons	7,626	9,545	0	17,171	38.05	0	0.00
Chromium Metal	short tons	8,895	44	0	8,939	133.02	718	10.68
Columbium	pounds Cb	1,149,956	168,212	0	1,318,168	45.11	0	0.00
Dysprosium	MT Oxide	0	0	47	47	21.64	47	21.64
Erbium	MT Oxide	0	0	124	124	12.43	124	12.43
Fluorspar Acid Grade	short tons	0	0	56,322	56,322	21.54	56,322	21.54
Gallium	kilograms	16,932	279	13,231	30,442	18.04	17,686	10.48
Germanium	kilograms	0	0	28,888	28,888	35.66	28,888	35.66
Manganese Metal-Electrolytic	short tons	0	0	7,406	7,406	22.96	7,406	22.96
Manganese Ore Chem/Metal Grade	short tons	70,198	4,353	0	74,550	0.39	0	0.00
Mercury	pounds	130,112	1,976	0	132,088	3.39	0	0.00
Rubber (natural)	long tons	232,840	5,049	0	237,889	1,158.74	0	0.00
Scandium	KG Oxide	0	0	572	572	0.77	572	0.77
Silicon Carbide	short tons	0	0	81,869	81,869	93.88	81,869	93.88
Strontium	metric tons Sr	2,089	71	0	2,160	3.68	0	0.00
Tantalum	pounds Ta	601,577	24,110	452,030	1,077,716	72.74	623,307	42.07
Terbium	MT Oxide	0	0	7	7	7.16	7	7.16
Thulium	MT Oxide	0	0	20	20	3.31	20	3.31
Tin	metric tons	0	0	19,428	19,428	416.09	19,428	416.09
Tungsten	pounds W	0	0	11,288,268	11,288,268	84.26	11,288,268	84.26
Yttrium	MT Oxide	0	0	1,899	1,899	85.17	1,899	85.17
Total $M value						2,672.22		1,221.41

Table 13-2 shows, for the alternative base case, the ratios (expressed as percentages) of the first year shortfalls to the first year material demands, and also the ratios of the total shortfalls (over the whole scenario) to the total demand. (Materials not listed in Table 13-2 do not have shortfalls in the alternative base case.) These ratios represent the portion of demand that is unmet by supply. The civilian shortfalls are all in the first year and form a substantial portion of the total shortfall, so the first year ratios are generally greater than the overall ratios—but not always. It is worth noting that while the rubber shortfall is large in dollar terms, it is only about three or four percent of the total rubber demand. In other words, the defense (plus emergency investment) demand for rubber is only about three or four percent of the total demand for rubber.

Table 13-2. Alternative Base Case Shortfall to Demand Ratios

	Shortfall to Demand Ratio (percent)	
Material	First Year	Over All Years
Aluminum Oxide Fused Crude	63.49	17.59
Antimony	59.92	16.33
Bauxite Metal Grade Jamaica & Suriname	3.50	3.25
Bismuth	48.23	12.50
Chromium Ferro (Ferrochromium)	2.95	0.81
Chromium Metal	18.86	18.97
Columbium	2.08	1.39
Dysprosium	18.23	5.44
Erbium	77.27	21.16
Fluorspar Acid Grade	6.41	1.69
Gallium	34.14	17.26
Germanium	48.16	13.10
Manganese Metal–Electrolytic	24.36	6.30
Manganese Ore Chem/Metal Grade	4.39	4.04
Mercury	4.06	4.32
Rubber (natural)	3.52	4.20
Scandium	61.57	21.54
Silicon Carbide	28.35	8.02
Strontium	4.47	4.82
Tantalum	22.09	11.52
Terbium	12.31	3.66
Thulium	77.87	23.97
Tin	22.95	6.56
Tungsten	25.73	7.00
Yttrium	75.62	23.32
Average	30.02	10.35

Peacetime Supply Disruption Scenarios

The peacetime supply disruption scenarios are intended to model the effects of a situation in which output from one particular designated country suddenly becomes unavailable for a year. The scenarios are one year in length. The underlying demands for goods and services reflect peacetime assumptions, namely:

- No demand to rebuild weapons lost in a conflict scenario.
- No homeland damage.
- No reductions in civilian demand to account for essential demand only.
- No emergency investment demand.
- No adjustments to exports or imports, except imports from the designated country are set to zero.

Similarly, the assumptions involving material supply are consistent with peacetime. That is, no decrements for war damage, country reliability, anti-U.S. sentiment, or shipping losses are applied—except for zeroing out the supply from the designated country. However, the same ramp-up of United States and foreign supply (except for the designated country) to capacity levels is assumed as in the Base Case. This is considered to be a response to the disruption.[3]

Three different peacetime disruption scenarios were modeled, each with a different designated country. The first involves an export cutoff from China: in an effort to coerce or punish the United States or other competitors, as well as to drive up commodity prices, China suspends exports to the United States for at least one year. The second scenario considers a similar export cutoff from Russia. The third scenario assumes that deterioration in South Africa's economy and infrastructure prompt an outbreak of civil unrest there, resulting in major disruptions to mining, transportation and export of strategic materials for at least one year. Since each of these countries is a significant supplier of certain materials (see Table 13-3), one might expect fairly large shortfalls of those materials to occur.

3 The 2011 Requirements Report to Congress also examined some peacetime supply disruption scenarios. But there is a fundamental difference in assumptions between those cases and the ones modeled for this (2013) report. In the peacetime supply disruptions scenarios examined for this report, defense demands have priority claim on all the defense-usable supply that is available. In the 2011 report peacetime supply disruption cases, only the normal, peacetime defense share of supply—on the order of five percent—could be used to satisfy defense demands. This led to large defense shortfalls in those cases.

Table 13-3. Study Materials Supplied by China, Russia, and South Africa

Material Name	China	Russia	South Africa
Aluminum Metal	China	Russia	South Africa
Aluminum Oxide Fused Crude	China		
Antimony	China	Russia	South Africa
Bauxite Metal Grade Jamaica & Suriname	China	Russia	
Bauxite Refractory	China	Russia	
Beryl Ore	China	Russia	
Beryllium Copper Master Alloy	China		
Beryllium Metal	China		
Bismuth	China	Russia	
Boron	China	Russia	
Cadmium	China	Russia	
Cerium	China		South Africa
Chromite Ore (all grades)	China	Russia	South Africa
Chromium Ferro (Ferrochromium)	China	Russia	South Africa
Chromium Metal	China	Russia	
Cobalt	China	Russia	South Africa
Columbium			
Copper	China	Russia	South Africa
Dysprosium	China		South Africa
Erbium	China		South Africa
Europium	China		South Africa
Fluorspar Acid Grade	China	Russia	South Africa
Fluorspar Metallurgical Grade	China	Russia	South Africa
Gadolinium	China		South Africa
Gallium	China	Russia	
Germanium	China	Russia	
Hafnium	China	Russia	
Holmium	China		South Africa
Indium	China	Russia	
Iridium (Platinum Group)		Russia	South Africa
Lanthanum	China		South Africa
Lead	China	Russia	South Africa
Lithium	China		
Lutetium	China		South Africa
Magnesium	China	Russia	
Manganese Dioxide Battery Grade Natural	China		
Manganese Dioxide Battery Grade Synthetic	China		South Africa

Table 13-3. Study Materials Supplied by China, Russia, and South Africa (concluded)

Material Name	China	Russia	South Africa
Manganese Ferro (C and Si)	China	Russia	South Africa
Manganese Metal Electrolytic	China		South Africa
Manganese Ore Chem/Metal Grade	China	Russia	South Africa
Mercury	China	Russia	
Molybdenum	China	Russia	
Neodymium	China		South Africa
Nickel	China	Russia	South Africa
Palladium (Platinum Group)		Russia	South Africa
Platinum (Platinum Group)		Russia	South Africa
Praseodymium	China		South Africa
Quartz Crystals (synthetic)		Russia	South Africa
Rhenium		Russia	
Rhodium (Platinum Group)		Russia	South Africa
Rubber (natural)	China		
Ruthenium (Platinum Group)		Russia	South Africa
Samarium	China		South Africa
Scandium (composite "other" producer includes China and Russia)			
Selenium	China	Russia	South Africa
Silicon	China	Russia	South Africa
Silicon Carbide	China	Russia	
Silver	China	Russia	South Africa
Strontium	China		
Tantalum	China		
Tellurium	China	Russia	
Terbium	China		South Africa
Thulium	China		South Africa
Tin	China	Russia	
Titanium (sponge)	China	Russia	
Tungsten	China	Russia	
Vanadium	China	Russia	South Africa
Ytterbium	China		South Africa
Yttrium	China		South Africa
Zinc	China	Russia	South Africa
Zirconium Metal	China	Russia	
Zirconium Ores & Concentrates	China	Russia	South Africa

Table 13-4 shows the shortfall results (for the 72 non-proprietary materials). All of the shortfalls are in the civilian sector (i.e., they represent unsatisfied civilian demand). In other words, in each case, there is sufficient supply from other countries to satisfy defense demand. (Since these are one-year scenarios, all the shortfalls occur in the first scenario year). As Table 13-4 indicates:

- In the first scenario (with China zeroed out), 21 materials have shortfalls, for a total shortfall value of $1.5 billion (using prices as of Spring 2012).
- In the second scenario (Russia zeroed out), three materials have shortfalls, for a total shortfall value of $531 million.
- In the third scenario (South Africa zeroed out), five materials have shortfalls, for a total shortfall value of $1.9 billion.

The total shortfall values are the same order of magnitude as the Base Case shortfall, $1.2 billion (excluding the extrinsically specified beryllium metal goal). It is to be expected that the first scenario has the most materials with shortfalls, since China is a major supplier of materials. Interestingly, the total dollar value of the shortfalls is highest in the third scenario, where supply from South Africa is zeroed out.

Table 13-4. Material Shortfalls in the Peacetime Supply Disruption Scenarios

		1. China zeroed out Total Shortfall		2. Russia zeroed out Total Shortfall		3. South Africa zeroed out Total Shortfall	
Material	Units	in units	in $M	in units	in $M	in units	in $M
Aluminum Metal	short tons	0	0.00	0	0.00	0	0.00
Aluminum Oxide Fused Crude	short tons	252,226	143.47	0	0.00	0	0.00
Antimony	short tons	25,027	201.81	0	0.00	0	0.00
Bauxite Metal Grade Jamaica & Suriname	short tons	0	0.00	0	0.00	0	0.00
Bauxite Refractory	long tons	4,424	2.18	0	0.00	0	0.00
Beryl Ore	short tons	0	0.00	0	0.00	0	0.00
Beryllium Copper Master Alloy	short tons	373	4.92	0	0.00	0	0.00
Beryllium Metal	short tons	0	0.00	0	0.00	0	0.00
Bismuth	pounds	4,012,808	43.76	0	0.00	0	0.00
Boron	MT Oxide	0	0.00	0	0.00	0	0.00
Cadmium	pounds	0	0.00	0	0.00	0	0.00
Cerium	MT Oxide	0	0.00	0	0.00	0	0.00
Chromite Ore (all grades)	short tons	0	0.00	0	0.00	0	0.00
Chromium Ferro (Ferrochromium)	short tons	0	0.00	0	0.00	0	0.00
Chromium Metal	short tons	0	0.00	2,618	38.96	0	0.00
Cobalt	pounds Co	0	0.00	0	0.00	0	0.00

Table 13-4. Material Shortfalls in the Peacetime Supply Disruption Scenarios (continued)

		1. China zeroed out		2. Russia zeroed out		3. South Africa zeroed out	
		Total Shortfall		Total Shortfall		Total Shortfall	
Material	Units	in units	in $M	in units	in $M	in units	in $M
Columbium	pounds Cb	0	0.00	0	0.00	0	0.00
Copper	short tons	0	0.00	0	0.00	0	0.00
Dysprosium	MT Oxide	87	40.19	0	0.00	0	0.00
Erbium	MT Oxide	139	14.01	0	0.00	0	0.00
Europium	MT Oxide	0	0.00	0	0.00	0	0.00
Fluorspar Acid Grade	short tons	93,374	35.72	0	0.00	0	0.00
Fluorspar Metallurgical Grade	short tons	0	0.00	0	0.00	0	0.00
Gadolinium	MT Oxide	0	0.00	0	0.00	0	0.00
Gallium	kilograms	20,174	11.95	0	0.00	0	0.00
Germanium	kilograms	30,121	37.18	0	0.00	0	0.00
Hafnium	metric tons	0	0.00	0	0.00	0	0.00
Holmium	MT Oxide	0	0.00	0	0.00	0	0.00
Indium	troy oz.	0	0.00	0	0.00	0	0.00
Iridium (Platinum Group)	troy oz.	0	0.00	0	0.00	60,013	37.92
Lanthanum	MT Oxide	0	0.00	0	0.00	0	0.00
Lead	short tons Pb	0	0.00	0	0.00	0	0.00
Lithium	metric tons	0	0.00	0	0.00	0	0.00
Lutetium	MT Oxide	0	0.00	0	0.00	0	0.00
Magnesium	short tons	12,896	43.30	0	0.00	0	0.00
Manganese Dioxide Battery Grade Natural	short tons	0	0.00	0	0.00	0	0.00
Manganese Dioxide Battery Grade Synthetic	short tons	0	0.00	0	0.00	0	0.00
Manganese Ferro (C and Si)	short tons	0	0.00	0	0.00	0	0.00
Manganese Metal--Electrolytic	short tons	7,920	24.55	0	0.00	0	0.00
Manganese Ore Chem/Metal Grade	short tons	0	0.00	0	0.00	0	0.00
Mercury	pounds	0	0.00	0	0.00	0	0.00
Molybdenum	pounds	0	0.00	0	0.00	0	0.00
Neodymium	MT Oxide	0	0.00	0	0.00	0	0.00
Nickel	short tons Ni	0	0.00	0	0.00	0	0.00
Palladium (Platinum Group)	troy oz.	0	0.00	731,716	491.71	638,268	428.92
Platinum (Platinum Group)	troy oz.	0	0.00	0	0.00	778,643	1,171.01
Praseodymium	MT Oxide	0	0.00	0	0.00	0	0.00
Quartz Crystals (synthetic)	metric tons	0	0.00	0	0.00	0	0.00
Rhenium pounds	pounds	8,140	16.11	0	0.00	0	0.00
Rhodium (Platinum Group)	troy oz.	0	0.00	0	0.00	88,670	314.55
Rubber (natural)	long tons	0	0.00	0	0.00	0	0.00

Table 13-4. Material Shortfalls in the Peacetime Supply Disruption Scenarios (concluded)

		1. China zeroed out Total Shortfall		2. Russia zeroed out Total Shortfall		3. South Africa zeroed out Total Shortfall	
Material	Units	in units	in $M	in units	in $M	in units	in $M
Ruthenium (Platinum Group)	troy oz.	0	0.00	0	0.00	54,220	12.91
Samarium	MT Oxide	0	0.00	0	0.00	0	0.00
Scandium	KG Oxide	515	0.70	208	0.28	0	0.00
Selenium	kilograms	0	0.00	0	0.00	0	0.00
Silicon	metric tons	0	0.00	0	0.00	0	0.00
Silicon Carbide	short tons	101,714	116.63	0	0.00	0	0.00
Silver	troy oz.	0	0.00	0	0.00	0	0.00
Strontium	metric tons Sr	0	0.00	0	0.00	0	0.00
Tantalum	pounds Ta	843,457	56.93	0	0.00	0	0.00
Tellurium	metric tons	0	0.00	0	0.00	0	0.00
Terbium	MT Oxide	15	14.88	0	0.00	0	0.00
Thulium	MT Oxide	23	3.77	0	0.00	0	0.00
Tin	metric tons	22,088	473.05	0	0.00	0	0.00
Titanium (sponge)	short tons	0	0.00	0	0.00	0	0.00
Tungsten	pounds W	11,597,806	86.57	0	0.00	0	0.00
Vanadium	short tons V	0	0.00	0	0.00	0	0.00
Ytterbium	MT Oxide	0	0.00	0	0.00	0	0.00
Yttrium	MT Oxide	2,058	92.30	0	0.00	0	0.00
Zinc	short tons	0	0.00	0	0.00	0	0.00
Zirconium Metal	short tons	0	0.00	0	0.00	0	0.00
Zirconium Ores & Concentrates	short tons	0	0.00	0	0.00	0	0.00
Total			1,463.98		530.95		1,965.30

Additional Sensitivity Cases

Appendix 3 has laid out the Base Case assumptions about demand and supply of materials, goods, and services. To examine the effects of these assumptions, a number of sensitivity cases were performed that varied one or more of them. This section summarizes the results. Table 13-5 shows a brief description of the sensitivity case and the total dollar value of the shortfalls for each economic sector (defense, emergency investment, and civilian). The shortfall values in Table 13-5 omit the extrinsically specified goal of $16.1 million for beryllium metal. The values include beryllium metal only to the extent that the supply-demand comparison found a shortfall for it.

The sensitivity cases described above have involved changes to the inputs of the Stockpile Sizing Module (see Appendix 7), which result in changes to the computed shortfall amounts. An additional category of sensitivity cases concerns changes to the computation of shortfall mitigation strategies. For example, the mitigation strategy derived in Appendix 11 considered four mitigation options in a given order: extra U.S. buys, substitution, reduced exports, and stockpiling. One could explore sensitivity cases that vary this order or consider additional mitigation options. Yet another category of sensitivity cases results from changing the probability of the scenario, which affects the costs of mitigation options (see Appendix 12).

Table 13-5. Selected Sensitivity Cases and their Shortfall Results

		Shortfalls in $ million				
Case Number	Brief Description	Defense	Emergency Investment	Civilian	Total	Percent of Base Case
1	2013 NDS Base Case	0.00	0.00	1,221.41	1,221.41	100.00
2	12-month ramp-up to capacity, U.S. and foreign	3.36	5.76	2,756.53	2,765.65	226.43
3	Combination of cases 2 and 8. Twelve-month ramp-up and only U.S. and Canadian supply can satisfy defense and emergency investment demand.	1,467.77	61.52	2,705.96	4,235.25	346.75
5	Six-month ramp-up to capacity for U.S., 12-month for foreign	3.36	5.76	1,794.81	1,803.93	147.69
6	50% expanded market share (extra U.S. buys option)	0.00	0.00	578.75	578.75	47.38
8	Alternative base case. Only U.S. and Canadian supply can satisfy defense and emergency investment demand.	1,419.91	56.89	1,195.42	2,672.22	218.78
10	Combination of cases 6 and 8. Expanded market share (50 percent) and only U.S. and Canadian supply can satisfy defense and emergency investment demand.	1,393.69	34.85	553.87	1,982.41	162.31
13	100 percent expanded market share--for a limiting case	0.00	0.00	416.57	416.57	34.11
14	Exports of goods and services set to zero throughout the scenario.	0.00	0.00	175.91	175.91	14.40
15	Civilian demands for goods and services are 90 percent of their Base Case values (decreases demand)	0.00	0.00	833.57	833.57	68.25
16	Case using 2011 NDS Study reliability values--otherwise like 2013 Base Case	0.00	0.00	1,385.97	1,385.97	113.47

Table 13-5. Selected Sensitivity Cases and their Shortfall Results (concluded)

		Shortfalls in $ millions				
Case Number	Brief Description	Defense	Emergency Investment	Civilian	Total	Percent of Base Case
17	Exports of goods and services set to zero in the first scenario year (cf. case 14, where they are set to zero throughout the scenario).	0.00	0.00	175.91	175.91	14.40
18	Exports of goods and services set to half their peacetime values in the first scenario year.	0.00	0.00	568.23	568.23	46.52
21	Exports of goods and services set to zero in the first scenario year and defense demands for goods and services are increased to account for essential defense exports.	0.00	0.00	177.52	177.52	14.53
22	Exports of goods and services set to half their peacetime values in the first scenario year and defense demands for goods and services are increased to account for essential defense exports. (This became the case for the reduced exports mitigation option.)	0.00	0.00	573.08	573.08	46.92
23	Substitution using new, updated factors as of August 2012.	0.00	0.00	740.11	740.11	60.59

Appendix 14
Essential Civilian Demand Factors

Introduction

The statute governing the NDS requires that the Biennial Report on Stockpile Requirements set forth the National Security Planning Assumptions used by the Secretary of Defense in determining recommendations for stockpile requirements.[1] Two of the planning assumptions specified in the statute address civilian requirements, namely:

- The military, industrial, and *essential civilian* requirements to support the national emergency
- *Civilian austerity* measures required during the mobilization period and military conflict

This appendix describes the process established by the DoD, after consultation with a civilian agency working group, to determine which civilian requirements should be considered essential.[2] The process uses percentage reduction factors to identify the portions of projected normal civilian demands deemed nonessential.[3] Essential civilian requirements are calculated by reducing projected demands by the percentages specified in the reduction factors. Only the decremented demands are considered essential and used in the determination of requirements for the materials included in this study.

The reduction factors serve to support key national security objectives while limiting potentially costly requirements for the materials included in this study. Requirements that are deemed essential can be grouped according to the following purposes:

- Procuring goods and services for defense.
- Sustaining supporting industries.
- Maintaining national economic strength.

---

1 See U.S. Code 50, § 98h-5.

2 Civil departments and agencies invited to participate in the essential civilian demand decision process included Agriculture, Commerce, Energy, Health and Human Services, Homeland Security, Housing and Urban Development, Interior, Labor, the Office of Management and Budget, State, Transportation, and Treasury.

3 Events during the crisis would influence civilian demands, both positively and negatively, across the four-year scenario. However, essential civilian demands are calculated based on forecasts of normal peacetime demands.

- Providing government services.
- Maintaining an adequate civilian standard of living.
- Recovering from an attack on the U.S. homeland.

Reduction factors are defined for 78 types of personal consumption and 31 types of construction, as shown in Tables 14-1 and 14-2 on the following pages.[4] As indicated in the tables, the factors are generally lower during year one of the four-year scenario. This allows for a period of transition to help the civilian sector adjust to developing material shortages.

Personal Consumption Expenditures

The 78 spending categories listed in Table 14-1 represent types of personal consumption. Generally, large reduction factors are specified for the various types of consumer durable goods, up to 75 percent for new automobiles, leisure vehicles, and jewelry. Consumer durables are targeted because their production is especially intensive in the use of the materials included in this study.[5] In light of potential energy shortages, gasoline and foreign travel are also targeted.

For a number of personal consumption categories, a "+" sign is displayed in lieu of a reduction factor. These sectors generally represent nondurable goods and services, sectors that make relatively little use of study materials. It is presumed that these items will be available in ample supply and that consumers will offset reductions in spending on consumer durables by spending more on these items. That is, spending in these categories will exceed projected normal spending.

A reduction factor of zero is indicated for a number of sectors. These sectors generally represent necessities and are mainly nondurable goods and services that do not make intensive use of study materials. The zero reduction factors indicate that projected spending is considered essential and that consumer spending will be in line with normal projections.

---

[4] These particular spending categories reflect the level of detail available in the simulation models used for the DoD NDS study, namely the Long-term Inter-industry Forecasting Tool (LIFT) and the Inter-industry Large-scale Integrated and Dynamic Model (ILIAD) input-output models developed by the Inter-industry Forecasting Project at the University of Maryland.

[5] Note that spending to replace consumer durables damaged during an attack on the U.S. homeland is considered essential. Similarly, construction to replace damaged assets is considered essential. The reduction factors on Tables 2-1 and 2-2 do not apply to such spending on homeland recovery.

Table 14-1. Percentage Reduction Factors to Eliminate Nonessential Consumption Spending[6]

Personal Consumption Categories		Conflict	Regeneration		
		Year 1	Year 2	Year 3	Year 4
1	New Cars	50.0	75.0	75.0	75.0
2	Used Cars	25.0	50.0	50.0	50.0
3	New & Used Trucks	25.0	50.0	50.0	50.0
4	Tires & Tubes	25.0	50.0	50.0	50.0
5	Auto Accessories & Parts	15.0	15.0	15.0	15.0
6	Furniture, Mattresses, Bedsprings	25.0	50.0	50.0	50.0
7	Kitchen, Household Appliances	25.0	50.0	50.0	50.0
8	China, Glassware, Tableware, Utensils	25.0	50.0	50.0	50.0
9	Radio, TV, Records, Musical Instruments	25.0	50.0	50.0	50.0
10	Floor Coverings	25.0	50.0	50.0	50.0
11	Durable House furnishings	25.0	50.0	50.0	50.0
12	Writing Equipment	25.0	50.0	50.0	50.0
13	Hand Tools	25.0	50.0	50.0	50.0
14	Jewelry	50.0	75.0	75.0	75.0
15	Ophthalmic & Orthopedic Appliances	0.0	0.0	0.0	0.0
16	Books & Maps	25.0	50.0	50.0	50.0
17	Wheeled Goods & Durable Toys	25.0	50.0	50.0	50.0
18	Boats, Recreational Vehicles & Aircraft	50.0	75.0	75.0	75.0
19	Food, Off Premise	0.0	0.0	0.0	0.0
20	Food, On Premise	0.0	0.0	0.0	0.0
21	Alcohol, Off Premise	0.0	0.0	0.0	0.0
22	Alcohol, On Premise	0.0	0.0	0.0	0.0
23	Shoes & Footwear	+	+	+	+
24	Women's Clothing	+	+	+	+
25	Men's Clothing	+	+	+	+
26	Luggage	+	+	+	+
27	Gasoline & Oil	25.0	50.0	50.0	50.0
28	Fuel Oil & Coal	0.0	0.0	0.0	0.0
29	Tobacco	+	+	+	+
30	Semi-durable House furnishings	+	+	+	+

[6] The values (including zeroes) in the table represent the percentage decrements imposed on projected civilian spending to eliminate non-essential items. For personal consumption, those categories with +'s are incremented proportionally so that total consumption across all the categories remains at the projected total level.

Table 14-1. Percentage Reduction Factors to Eliminate Nonessential Consumption Spending (Continued)

Personal Consumption Categories		Conflict	Regeneration		
		Year 1	Year 2	Year 3	Year 4
31	Drug Preparations & Sundries	+	+	+	+
32	Toilet Articles & Preparations	+	+	+	+
33	Stationery & Writing Supplies	+	+	+	+
34	Non-durable Toys & Sport Supplies	+	+	+	+
35	Flowers, Seeds, Potted Plants	+	+	+	+
36	Cleaning Preparations	+	+	+	+
37	Lighting Supplies	+	+	+	+
38	Household Paper Products	+	+	+	+
39	Magazines & Newspapers	+	+	+	+
40	Other Non-durables	+	+	+	+
41	Owner Occupied Space Rent	+	+	+	+
42	Tenant Occupied Space Rent	+	+	+	+
43	Hotels, Motels	+	+	+	+
44	Other Housing	0.0	0.0	0.0	0.0
45	Electricity	0.0	0.0	0.0	0.0
46	Natural Gas	0.0	0.0	0.0	0.0
47	Water & Other Sanitary Services	+	+	+	+
48	Telephone & Telegraph	+	+	+	+
49	Domestic Services	+	+	+	+
50	Household Insurance	+	+	+	+
51	Other Household Operations: Repair	+	+	+	+
52	Postage	0.0	0.0	0.0	0.0
53	Auto Repair	+	+	+	+
54	Bridge, Tolls, etc.	+	+	+	+
55	Auto Insurance	+	+	+	+
56	Taxicabs	+	+	+	+
57	Local Public Transport	+	+	+	+
58	Intercity Railroad	+	+	+	+
59	Intercity Busses	+	+	+	+
60	Airlines	+	+	+	+
61	Travel Agents, Other Transportation Services	0.0	0.0	0.0	0.0
62	Laundries & Shoe Repair	+	+	+	+
63	Barbershops & Beauty Shops	+	+	+	+
64	Physicians	0.0	0.0	0.0	0.0
65	Dentists & Other Professional Services	0.0	0.0	0.0	0.0

Table 14-1. Percentage Reduction Factors to Eliminate Nonessential Consumption Spending (Concluded)

Personal Consumption Categories		Conflict	Regeneration		
		Year 1	Year 2	Year 3	Year 4
66	Private Hospitals & Sanitariums	+	+	+	+
67	Health Insurance	+	+	+	+
68	Brokerage & Investment Counselors	+	+	+	+
69	Bank Service Charges & Services	+	+	+	+
70	Life Insurance	+	+	+	+
71	Legal Services	+	+	+	+
72	Funeral Expenses, Other Personal Business	+	+	+	+
73	Radio & TV Repair	+	+	+	+
74	Movies, Theatre, Spectator Sports	+	+	+	+
75	Other Recreational Services	+	+	+	+
76	Education	+	+	+	+
77	Religious & Welfare Services	+	+	+	+
78	Foreign Travel	50.0	75.0	75.0	75.0

Construction

The 31 spending categories shown on Table 14-2 represent various types of construction. Because construction generally makes intensive use of study materials, the reduction factors for some of these categories are quite high, rising to 67.5 percent for residential construction and 50 percent for several commercial sectors. However, all government construction is considered essential as is private construction of transport, communications, and energy infrastructure. In these cases, the reduction factor is zero and spending is presumed to be in line with normal projections.

Table 14-2. Percentage Reduction Factors to Eliminate Nonessential Construction Spending

Construction Categories		Conflict	Regeneration		
		Year 1	Year 2	Year 3	Year 4
1	1 Unit Residential Structures	50.0	67.5	67.5	67.5
2	2 Or More Unit Residential Structures	50.0	67.5	67.5	67.5
3	Mobile Homes	0.0	0.0	0.0	0.0
4	Additions & Alterations	50.0	67.5	67.5	67.5
5	Hotels, Motels, Dormitories	25.0	50.0	50.0	50.0
6	Industrial	25.0	50.0	50.0	50.0
7	Offices	25.0	50.0	50.0	50.0
8	Stores, Restaurants, Garages	25.0	50.0	50.0	50.0
9	Religious	25.0	50.0	50.0	50.0
10	Educational	0.0	0.0	0.0	0.0
11	Hospital & Institutional	0.0	0.0	0.0	0.0
12	Misc. Nonresidential Buildings	25.0	50.0	50.0	50.0
13	Farm Buildings	0.0	0.0	0.0	0.0
14	Mining Exploration Shafts & Wells	0.0	0.0	0.0	0.0
15	Railroads	0.0	0.0	0.0	0.0
16	Telephone & Telegraph	0.0	0.0	0.0	0.0
17	Electric Light & Power	0.0	0.0	0.0	0.0
18	Gas & Petroleum Pipes	0.0	0.0	0.0	0.0
19	Other Structures	0.0	0.0	0.0	0.0
20	Highways & Streets	0.0	0.0	0.0	0.0
21	Military Facilities	0.0	0.0	0.0	0.0
22	Conservation	0.0	0.0	0.0	0.0
23	Sewer Systems	0.0	0.0	0.0	0.0
24	Water Supply Facilities	0.0	0.0	0.0	0.0
25	Residential (Public)	0.0	0.0	0.0	0.0
26	Industrial (Public)	0.0	0.0	0.0	0.0
27	Educational (Public)	0.0	0.0	0.0	0.0
28	Hospital (Public)	0.0	0.0	0.0	0.0
29	Other Buildings (Public)	0.0	0.0	0.0	0.0
30	Misc. Public Structures	0.0	0.0	0.0	0.0
31	Broker's Commission (Residential Structures)	50.0	67.5	67.5	67.5

Appendix 15
Country Reliability Protocol

Introduction

The Defense Intelligence Agency (DIA) was provided with a list of questions (see Table 15-1 below) to perform their country reliability evaluations for the 2013 National Defense Stockpile (NDS) requirements analysis. DIA's Defense Resource and Infrastructure Office, Defense Industry Division, has regional materials experts that have been performing this assessment for DLA Strategic Materials for many years. Their office considers approximately 175 countries aggregated into four regions. They monitor and track materials issues on an ongoing basis. In addition, the regional offices collaborate with each other to ensure that assessments are consistent and properly account for any latest developments.

Questions Used in the 2013 National Defense Stockpile Requirements Report

Table 15-1. Questions Posed to DIA Concerning Country Reliability

Question 1: Ability to Supply During Base Case Conflict Scenario

Please assess—in the context of the Base Case NDS conflict scenario (description provided)—the likely degradation in country X's ability to supply Strategic and Critical Materials (S&CMs) to world markets.

Please use a scale of 0-100 percent, with 100 percent meaning fully able (no degradation) and 0 meaning totally unable (complete degradation).

Ignore *direct* wartime damage (e.g., bombing damage) in your estimates. Consider other factors likely to affect supply during a Base Case scenario, e.g., power shortages, transportation breakdowns, labor strife, civil unrest, or *indirect* effects of Base Case conflicts.

Distinguish between year 1 (the conflict year) and years 2-4 (the three regeneration years). If you wish to input different values for the various regeneration years, please do so.

Question 2: Willingness to Sell to U.S. During Base Case Conflict Scenario

Please also assess—in the context of the same Base Case NDS conflict scenario—the extent of willingness of country X to sell S&CMs to the United States.

Please use a scale of 0-100 percent, with 100 percent meaning fully willing and 0 meaning totally unwilling.

This question asks specifically about anti-U.S. sentiment and orientation.

Distinguish between year 1 (the conflict year) and years 2-4 (the three regeneration years). If you wish to input different values for the various regeneration years, please do so.

Question 3: General Reliability (Ability/Willingness) in Near-Term Ongoing Environment

Please assess the general reliability (ability/willingness) of country X to supply S&CMs to the United States over the next 2-3 years—in the context of the conditions you believe most likely to prevail (as opposed to the Base Case conflict scenario). Consider factors such as those mentioned in Questions 1 and 2, and also economic and market factors.

Please use a scale of 0-100 percent, with 100 percent meaning fully able and willing to sell to the United States and 0 meaning totally unable or unwilling. For Question 3, one value encompasses both ability and willingness.

Your Explanations Are Welcome

You are invited (but certainly not required) to provide explanatory notes regarding any factors that influenced your determination of country ability or willingness. Insert comments in the cells of the response spreadsheet or put comments on an additional worksheet or file.

Appendix 16
Export Reductions

Introduction

The materials needed to produce the goods and services exported by the United States constitute a source of material demand. If exports of goods and services were reduced, U.S. demand for material would tend to be lower, and hence, material shortfalls would tend to be smaller (possibly zero). The U.S. government would not necessarily take active steps to reduce exports, even in a national emergency. In this context, reducing exports simply means that the U.S. government would not guarantee the availability of materials to produce goods for export. The treatment is similar to that of essential civilian demand: civilian austerity might not, in fact, be imposed in a national emergency, but the government will stockpile materials (or take other mitigation measures) to provide for only that portion of civilian demand that is considered essential.[1]

Background, Concepts, and Modeling

Goods and Services

The economic forecasting models from the University of Maryland (see Appendix 7), which forecast defense demand and civilian demand for goods and services, also forecast imports and exports of goods and services (for each of 360 different sectors of the economy), under peacetime (baseline, steady-state) conditions. The effects of an emergency scenario on imports and exports can be modeled by making adjustments to the forecasted values. Imports are generally decremented to take into account the (un)reliabilities of the particular countries of origin and the availability of goods from adversary countries (for some period of time). Exports are often decremented judgmentally to reflect the fact that the United States might need some of the goods that it otherwise would export (or the material needed to produce these goods). In the Base Case, most exports of goods and services are set to about 85 percent of their forecasted peacetime values, for most sectors of the economy, in all years of the scenario.

[1] This approach assigns a low priority to ensuring that materials would be available to support a portion of exports but would not directly reduce private demands for those materials. In practice, the government might find it necessary to allocate selected materials among end uses to ensure that essential requirements were met and that limited supplies were not diverted to lower priority issues.

Material Demands

Goods produced for export constitute a source of material demand. Conversely, materials contained in imports of finished goods lessen the demand for the materials needed to produce such goods domestically. Accordingly, when the material demand is computed from industrial demand (see Appendix 7), exports are added and imports are subtracted from the demand for goods and services. The economic forecasting models do not distinguish between defense-related imports and exports and civilian-related ones; a decision was made in the modeling process to add net exports to the civilian demand. More specifically, net exports (exports minus imports) in an economic sector are added to civilian demand in that sector and the resultant amount is multiplied by the material consumption ratio to yield a material demand amount that is considered to be civilian. Thus, in the current version of the modeling process, cutting imports has the effect of raising the civilian demand for materials and cutting exports has the effect of lowering the civilian demand for materials. (The defense material demand is computed by multiplying the material consumption ratio by the defense industrial demand—without any net export addition.) In other words, adjustments to the material demands to be considered when computing stockpile (or other shortfall mitigation) requirements can be modeled by adjusting the amounts of imports and exports of goods and services, even if the government will not explicitly try to affect imports and exports.

Specific Adjustments for Reduced Exports Sensitivity Case

A sensitivity case was performed to examine the effect of setting exports to 50 percent of their peacetime values (as opposed to about 85 percent in the Base Case), for each of the 360 economic sectors modeled. Because of a concern that some important defense-related exports might be subsumed in this adjustment, a special increase of $24 billion was made to the defense demand. This is the amount of foreign military-related exports in 2010 (the latest year for which data were available). The amount was allocated over the 360 economic sectors. Note that, in the current modeling process, lowering exports reduces the civilian demand for materials, but this extrinsic adjustment has been made to defense demand. Thus, there is a chance that the model will compute that defense shortfall occurs. But that in fact did not happen, and the total shortfalls decreased substantially from the Base Case, as reported below.

Results of Reduced Exports Sensitivity Case

Table 16-1 shows the material shortfalls in the sensitivity case, along with all the materials that have shortfalls in the Base Case and their Base Case shortfalls (including the extrinsically specified stockpile goal for beryllium metal). Total shortfall decreased from $1.2 billion in the Base Case to $589 million, a decrease of over 50 percent. Four of the 19 shortfall materials in the Base Case do not have any shortfalls in this sensitivity case: chromium metal, acid-grade fluorspar, tantalum, and terbium. Only 15 materials (of the 72 non-proprietary materials examined) have shortfalls. As in the Base Case, all shortfalls occurring in the first year of the scenario represent unsatisfied civilian demand.

Table 16-1. Effect of Export Reductions on Base Case Material Shortfalls

Material	Units	Base Case Shortfalls		Shortfalls with Reduced Exports		Difference	
		in units	in $M	in units	in $M	in units	in $M
Aluminum Oxide Fused Crude	short tons	231,485	131.67	171,413	97.50	60,072	34.17
Antimony	short tons	22,575	182.04	16,769	135.22	5,805	46.81
Beryllium Metal	short tons	52	16.12	52	16.12	0	0.00
Bismuth	pounds	3,629,659	39.59	2,334,425	25.46	1,295,234	14.13
Chromium Metal	short tons	718	10.68	0	0.00	718	10.68
Dysprosium	MT Oxide	47	21.64	1	0.60	46	21.05
Erbium	MT Oxide	124	12.43	95	9.51	29	2.92
Fluorspar Acid Grade	short tons	56,322	21.54	0	0.00	56,322	21.54
Gallium	kilograms	17,686	10.48	4,546	2.69	13,140	7.79
Germanium	kilograms	28,888	35.66	20,052	24.75	8,836	10.91
Manganese Metal-Electrolytic	short tons	7,406	22.96	3,781	11.72	3,624	11.23
Scandium	KG Oxide	572	0.77	510	0.69	62	0.08
Silicon Carbide	short tons	81,869	93.88	48,980	56.17	32,888	37.71
Tantalum	pounds Ta	623,307	42.07	0	0.00	623,307	42.07
Terbium	MT Oxide	7	7.16	0	0.00	7	7.16
Thulium	MT Oxide	20	3.31	14	2.27	6	1.05
Tin	metric tons	19,428	416.09	4,438	95.05	14,990	321.04
Tungsten	pounds W	11,288,268	84.26	6,282,064	46.89	5,006,204	37.37
Yttrium	MT Oxide	1,899	85.17	1,439	64.55	460	20.62
Total			1,237.53		589.20		648.33

For most of the materials, the reduced amount of material demand that arises from the export reductions is not enough to eliminate the Base Case shortfalls. But as noted above, for four materials it is enough—and the demand reduction in the first scenario year exceeds the Base Case shortfall amount. Table 6-2 shows the two quantities, for these materials. This distinction is important because the results reported in Table 16-1 assume that the export reductions are perfectly successful. When evaluating the effectiveness of export reduction as a shortfall mitigation option, it might be desirable to estimate or postulate a probability of success for this option and only consider the expected value of the reduced demand amount. Such a calculation underlies the results reported in the main document. See Appendix 11 for more information.

Table 16-2. Shortfall Difference and First Year Demand Reduction for Selected Materials

Material	Units	Shortfall Difference (equals Base Case shortfall)	First Year Demand Reduction
Chromium Metal	short tons	718	3,320
Fluorspar Acid Grade	short tons	56,322	174,638
Tantalum	pounds Ta	623,307	815,374
Terbium	MT Oxide	7	12

Appendix 17
Abbreviations/Acronyms

Av Oz	-	Avoirdupois Ounce (28.350 Grams)
$B	-	Billions of dollars
C	-	Carbon
Cb	-	Columbium (Niobium)
CEA	-	Council of Economic Advisors
Co	-	Cobalt
CT	-	Carats
DIA	-	Defense Intelligence Agency
DLA	-	Defense Logistics Agency
DoD		Department of Defense
FL	-	Flasks (76 Pounds)
FP	-	Future Price
FYDP	-	Future Years Defense Program
GDP	-	Gross domestic product
HPP	-	Hot pressed powder
IDA	-	Institute for Defense Analyses
ILIAD	-	Inter-industry Large-scale Integrated and Dynamic Model
INFORUM	-	Inter-industry Forecasting Project at the University of Maryland
IRAMM	-	Integrated Risk Assessment and Management Model
KG	-	Kilograms
KT	-	Kiloton
LB	-	Pounds
LB Cb	-	Pounds of Contained Columbium
LB Co	-	Pounds of Contained Cobalt
LB Ta	-	Pounds of Contained Tantalum
LB W	-	Pounds of Contained Tungsten
LCT	-	Long Calcined Tons
LDT	-	Long Dry Tons
LED	-	Light-emitting diode
LIFT	-	Long-term Inter-industry Forecasting Tool
LT	-	Long Tons (2240 Pounds)
$M	-	Millions of dollars

MCR	-	Material consumption ratios
MT	-	Metric Tons (2204.6 Pounds)
MT Oxide	-	Metric Tons of Oxide
MT Sr	-	Metric Tons of Contained Strontium
NATO	-	North Atlantic Treaty Organization
NDS	-	National Defense Stockpile
Ni	-	Nickel
NPV	-	Net present value
OMB	-	Office of Management and Budget
OSD	-	Office of the Secretary of Defense
Pb	-	Lead
PC	-	Pieces
RAMF-SM	-	Risk Assessment and Mitigation Framework for Strategic Materials
S&CM	-	Strategic and Critical Materials
SDT	-	Short Dry Tons
SF	-	Square Foot
Si	-	Silicon
SME	-	Subject matter expert
Sr		Strontium
ST	-	Short Tons (2000 Pounds)
ST V	-	Short Tons of Contained Vanadium
Ta	-	Tantalum
Tr Oz	-	Troy Ounces
US	-	United States
USC	-	United States Code
USGS	-	U.S. Geological Survey
V	-	Vanadium
W	-	Tungsten
WMD	-	Weapons of Mass Destruction