U.S. Dependence on Strategic Materials from Southern African Nations

Patrick D. Allen, Peter C. Noehrenberg
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Patrick D. Allen, Peter C. Noehrenberg

Prepared for the Office of the Secretary of Defense

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PREFACE

This Report documents the results of a RAND study to determine the current U.S. dependency on materials from southern African nations. This quick-response study was requested by the Deputy Assistant Secretary of Defense (African Affairs). The results should be of interest to anyone concerned with the global issue of strategic materials and the U.S. dependence on such materials.

The work was performed by RAND's National Defense Research Institute (NDRI), a federally funded research and development center sponsored by the Secretary of Defense and the Joint Staff. The study was made possible by NDRI's discretionary research support funds; it was coordinated among three programs within NDRI: International Security and Defense Strategy, Acquisition and Support Policy, and Applied Science and Technology.
SUMMARY

PURPOSE

The purpose of this study was to determine the United States' current and projected (end of the decade) reliance on southern African nations for materials the United States considers strategic. This single topic also required the consideration of a number of related topics, such as

- How does the United States determine which materials are strategic?
- Which materials do we expect to be on the strategic materials list by the end of the decade?
- What would the impact on U.S. national security interests be of a disruption or cutoff of supplies from southern African nations?
- Are there alternative sources for these strategic materials, and where are they located?
- Can alternative materials be substituted for some of the strategic materials in specific applications?
- How could the United States reduce its dependency on materials originating from southern African nations?

Defining Strategic Materials

The Department of Defense (DoD) determines which materials are strategic and critical under statutory guidance in the Strategic and Critical Materials Stockpiling Act (50 U.S.C. 98 et seq.). This act creates a National Defense Stockpile of these materials based on estimated needs in a national emergency. The act also authorizes research and development of substitutes and conservation measures.

Under the act, DoD determines the U.S. dependence on strategic materials in three areas: the requirements of our military ($2.3 billion in January 1991 prices), requirements of the industrial sector ($11 million), and essential civilian needs ($1.0 billion) under mobilization conditions, including civilian austerity measures (DoD, 1992). These demands are then compared to U.S. production of these materials (if any) and to anticipated imports based on foreign production adjusted for projected war damage, shipping losses, reliability of suppliers, and U.S. market share. Materials for which the United States has been
found to be in need are considered strategic, and Congress has authorized these to be included in the National Defense Stockpile.

The strategic stockpile list currently consists of 66 materials. The size of the stockpile requirement for each material is defined as a function of an assumed threat for planning purposes. The planning guidance is based on a statutorily mandated three-year conventional war and a warning period that is based on intelligence estimates. Although recent world events have significantly reduced the likelihood of this type of threat, Congress has not altered the three-year war-planning requirement. However, DoD has plans to lengthen the warning period beyond the one year used in recent estimates. In addition, because of reductions in the estimated force structure in response to the reduced threats, estimates of stockpile requirements are declining.

Predicting Future Demand for Strategic Materials

Predicting future demand for these materials is difficult, especially when there are so many intermediate producers between those who use the raw material and those who produce a finished product. For example, a superalloy producer may use cobalt to make a superalloy. A subcontractor may use the alloy to produce a turbine blade. Another subcontractor uses the blade to build a turbine engine. The primary contractor uses the turbine engine in a plane or a tank. Although historical data exist on strategic material demand and current trends, few data exist on estimated future demand and future trends for each strategic material.

However, we believe that the composition of demand for strategic materials will not change significantly by the end of the decade. Three factors contribute to this belief: the magnitude of current use, inertia in the major industries, and a decreased military budget. Because of the large quantity of strategic materials that the U.S. military, industrial, and civilian sectors use, it is unlikely that any shift from the current mix of materials in all or most applications will be rapid. Second, some industries, such as steel, electronics, and superalloys, have very precise methods of operation, making changes in their processes very difficult, time-consuming, and expensive. Third, as the military forces draw down, it is unlikely under current budget constraints that the composition of the military sector's demand for strategic materials will change significantly. As a result of these three factors, we do not anticipate a major shift in the composition of the demand for strategic materials by the end of the decade.
SCOPE AND APPROACH OF THE STUDY

The nations considered in this study are Botswana, Lesotho, Mozambique, Namibia, the Republic of South Africa, Swaziland, Zaire, Zambia, and Zimbabwe. Although Zaire is considered a central African nation, it was included because of its strategic significance as a producer of cobalt and other strategic materials. When we refer to southern African nations in this document, Zaire is included unless otherwise specified.

We began by identifying the southern African strategic materials upon which the United States is dependent. Our approach was based on an examination of global production of strategic materials, rather than on a detailed assessment of military demand for specific materials. The current list of 66 strategic materials was reduced to the 22 strategic materials that come from southern African nations. This list was further reduced to include only those for which at least 10 percent of their world production comes from southern African nations: antimony, chromium, cobalt, industrial diamond, manganese, platinum group metals (PGMs), titanium, and vanadium. Upon closer examination, we found that the United States does not depend on southern African nations for antimony, industrial diamond, and titanium. We also examined the four primary options, to hedge against these dependencies, and how they apply to the remaining five strategic materials.

CURRENT U.S. DEPENDENCE ON MATERIALS FROM SOUTHERN AFRICAN NATIONS

This study indicates that the United States is very dependent on two strategic materials (chromium and cobalt) and somewhat dependent on three other strategic materials (manganese, PGMs, and vanadium) from southern and central African nations. See Table S.1 for a summary of these results.

The U.S. steel industry is the primary reason for U.S. dependence on chromium and manganese. The United States produces an average of between 75 and 100 million tons of steel each year, all of which requires manganese of consistent grade and with few impurities. Inconsistencies or unknown impurities in the alloy originating from the ore can make a batch of steel useless. The Republic of South
<table>
<thead>
<tr>
<th>Strategic Material</th>
<th>Production Location</th>
<th>Substitute Sources</th>
<th>Produced As</th>
<th>Use or Demand</th>
<th>Recyclable</th>
<th>Substitute Materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chromium</td>
<td>Southern African nations</td>
<td>No(^a)</td>
<td>Main product</td>
<td>Stainless steel(^b)</td>
<td>Not reliably</td>
<td>No</td>
</tr>
<tr>
<td>Cobalt</td>
<td>Central African nations</td>
<td>Yes, but not in sufficient quantities</td>
<td>Byproduct</td>
<td>Alloys(^c) Catalysts Paints(^d) Additives(^f)</td>
<td>Yes</td>
<td>Some</td>
</tr>
<tr>
<td>Manganese</td>
<td>Widespread</td>
<td>Yes(^g)</td>
<td>Main product</td>
<td>Steel industry Alloys</td>
<td>Yes(^h)</td>
<td>No(^i)</td>
</tr>
<tr>
<td>PGMs</td>
<td>Widespread</td>
<td>Yes(^g)</td>
<td>Coproduct Byproduct Main product</td>
<td>Electronics Catalysts Synthetic fiber production(^k)</td>
<td>Yes</td>
<td>No(^j)</td>
</tr>
<tr>
<td>Vanadium</td>
<td>Widespread(^d)</td>
<td>Yes</td>
<td>Coproduct Byproduct</td>
<td>Steel and titanium alloys Catalyst(^n)</td>
<td>No</td>
<td>Yes(^m)</td>
</tr>
</tbody>
</table>
Table S.1—continued

*The U.S. steel industry requires consistent grades of chromite, which are available only from southern African nations.

*Over one million tons of stainless steel are produced each year, containing an average of 17 percent and a minimum of about 11 percent chromium.

*Cobalt is used as an alloy in superalloys, cemented carbides, and magnets.

*Cobalt is used both as a pigment and as a drying agent for paints.

*Cobalt does not show up well on infrared sensors and, therefore, is used in camouflage paints.

*Cobalt bonds organics to metals, such as in the production of belted tires.

*One of the most economical concentrations is in South Africa.

*The steel industry recycles manganese as an incidental component of steel scrap.

*For economic and metallurgical reasons, the U.S. steel industry requires consistent grades of manganese to produce 75 to 100 million tons of steel annually.

*Gold may be used as a substitute but is very expensive.

*Palladium is required in spinnerets that produce high-quality carbon fiber.

*Vanadium is distributed worldwide but at low concentrations.

*Vanadium substitutes do not have as good a strength-to-weight factor. There is no substitute for vanadium as a titanium alloying agent.

*Vanadium is a key catalyst in the production of sulfuric acid, which is used heavily in chemical and munitions production industries.
Africa is a supplier of high-grade ore that is particularly desirable because of its low phosphorus content.\(^1\)

The United States also produces one million tons of stainless steel each year, all of which requires a minimum of about 11 percent and an average of 17 percent chromium. Once again, southern African nations provide the grade consistency and known impurities that are essential to the production of high-quality stainless steel. The magnitude of use of both manganese and chromium makes it unlikely that there will be a significant shift in the use of these elements and metals by the end of the decade. Steel, both stainless and otherwise, is extremely important to the defense industry.

The United States is also dependent on cobalt, PGMs, and vanadium. Cobalt has many unique uses and properties: as a superalloy component, in cemented carbides, as a bonding material for enamels and metals, in magnets, as a catalyst in the oil and chemical industries, a paint dryer, and in camouflage paints for reducing detectability by infrared sensors. PGMs are used extensively in electronics and in the production of advanced carbon-fiber materials. Vanadium is an essential element in high-strength steels and in the production of sulfuric acid, a key ingredient in the chemical and munitions industries.

The southern African nations have the lowest-cost significant deposits for producing cobalt, PGMs, and vanadium. All three of these materials are produced as byproducts or coproducts, thereby making them more economical than if they were mined alone.\(^2\) Nations with smaller economical deposits cannot compete as well in the open market. Because of the long lead times in mine development, it is unlikely that the United States would be able to compensate quickly for a sudden shortage in these three materials. The United States can expect significant price increases for products that require cobalt, and possibly PGMs and vanadium, in the event of a shutdown in their supply. The cobalt crisis of 1978–1979 was a good example of the effects of this dependency and the short-term effects on prices because of reduced availability.

\(^{1}\)It takes time to remove phosphorous from steel; high-phosphorus steel is very hard; and there is little current market for high-phosphorus steel.

\(^{2}\)The production rates of the byproducts and coproducts also depend on the economics of the primary mineral and the coproduct mineral, respectively.
HEDGING AGAINST DEPENDENCIES

The United States has used four options to hedge against these dependencies:

- Purchasing and stockpiling strategic materials,
- Providing incentives for domestic production of strategic materials,
- Seeking alternative sources of the same materials, and
- Developing alternative materials.

The alternative sources option includes recycling efforts, while the alternative materials option includes conservation, replacement, and substitution efforts. Described below are the advantages and disadvantages of each option, as well as the current status of each as applied to the five selected strategic materials.

Stockpile Purchases

The advantage of stockpiling is that the stockpile can protect us from the worst-case scenario of a protracted conventional war. A second suggested advantage of using the stockpile to protect against economic shocks is not currently feasible, because it is illegal to use the stockpile for economic reasons. The disadvantages are that stockpiles are expensive and not necessarily efficient for those materials required by industries having rapid changes in specific production requirements, such as the electronics industry. Even though the overall demand for the material may be relatively constant, the form or grade of the material may be adequate one day and inadequate the next. In addition, selling stockpiled materials immediately shocks both the domestic and foreign materials industries. Although the stockpile could also be used to mitigate shocks in the strategic materials market, there is no legal basis for using the stockpile except in a national emergency.

The current stockpile levels of chromium, cobalt, and manganese are good, but the levels for PGMs and vanadium are poor relative to regulated goal levels. Unless the lower stockpile goals for these materials recommended by OSD are enacted into law, there will continue to be a significant shortfall in PGMs and vanadium. The good news is that the stockpile status is best for those strategic materials for which we have no or little domestic production capability.
Industry Incentives

The advantage of providing incentives to existing domestic producers is that it helps fund existing operations that may be facing economic difficulty. The disadvantages are that this option will continue the depletion of domestic resources, will invest in an industry that is less competitive economically, and is only applicable in cases where operations still exist.

For economic reasons, most of our domestic production capabilities for strategic materials no longer exist, so this option does not exist for most strategic materials. However, there are significant domestic recycling industries for chromium, cobalt, manganese, and PGMs, and there is a domestic vanadium production industry that processes imported residues containing vanadium. Industrial incentives would be best applied to securing the import of vanadium residues for domestic processing and to supporting the domestic recycling industries for chromium, cobalt, manganese, and PGMs.

Alternative Sources

The advantage of researching alternative sources is that locating them would make us less dependent on existing sources of these materials. The disadvantages are that there is no guarantee that such research would be successful, and even if it were, there is a long lead time before the discovery could be put into production. One area of ongoing research is the undersea mining of manganese.

Recycling affords several possible areas of effort. For example, recycling provides 21 percent of the domestic consumption of chromium and 16 percent of the domestic consumption of cobalt. About half of the U.S. exports of PGMs goes to foreign recycling centers. Manganese is recycled as a component of scrap steel.

The most promising areas for funding alternative source research are in undersea sources of manganese and in incentives to improve the domestic recycling industries for chromium, cobalt, and PGMs.

Alternative Materials

The advantages of researching alternative materials is that success would reduce our dependence on strategic materials, and any resulting proprietary technology may help the U.S. economy and balance of trade. The disadvantage is that searching for alternative materials is even more risky than searching for alternative sources of the same material, and, again, there is no guarantee that the research will
yield viable alternatives. In addition, certain types of research are costly and time-consuming, such as the testing of alloys for use in jet engines.

Congressional allocations have been proposed to use some of the stockpile budget to fund alternative materials research. Since the purpose of the national stockpile is to reduce the dependence of the United States on strategic materials in time of need, and not just to have a full stockpile, this is a reasonable endeavor to undertake with these funds.

Research into the substitution or replacement of strategic materials appears feasible in the following areas: chromium replacement in refractories, superalloys, and chemical processes; cobalt replacement in superalloys, magnets, machinery, catalysts, and paint; manganese substitution in superalloys and deoxidizers; and vanadium substitution in chemical processes. One area of concern is that many of the alternative materials are also strategic materials, some of which also originate in southern African nations. Even technologies that use "common materials" (e.g., carbon fibers and ceramics) sometimes rely on strategic materials, such as PGMs for spinnerets used to produce carbon fiber thread.
ACKNOWLEDGMENTS

The project could not have been completed without extensive and expert assistance from every sector. Lt. Col. Michael Harvin (OSD/ISA/AFR) was our project's action officer and our first point of contact. John Babey of the Defense National Stockpile Center of the Defense Logistics Agency provided the list of strategic materials, identified a contact at the Minerals Information Center, and provided many other leads. Paul Halpern of the Office of the Assistant Secretary of Defense (Production and Logistics) provided additional guidance and clarified the requirement-definition process. At the Bureau of Mines, Linda Carrico of the Minerals Information Center provided a large amount of useful and detailed information on each of the strategic materials and helped arrange the interviews at the Bureau of Mines. Harry Makar, Chief, and Scott Sibley, Assistant Chief, Branch of Metals, Bureau of Mines, coordinated the interviews with each of the commodity specialists. Special thanks go to all of the commodity specialists at the Bureau of Mines who gave their time and information: John Papp (chromium), Kim Shedd (cobalt), Thomas Jones (manganese), Roger Loebenstein (platinum), Henry Hilliard (vanadium), and Thomas Llewellyn (antimony). Deborah Kramer (titanium) supplied a written summary, while Anthony Peters (steel), Gerald Houch (steel), and Gordon Austin (industrial diamond) provided follow-up information by phone. George Morgan (southern Africa) and Hendrik G. van Oss (South Africa) offered insights into issues related to material production in that part of the world. John Morgan, Chief, Staff Officer, Bureau of Mines provided an historical perspective as well as an overview of current issues involving the National Strategic Stockpile. Additional information was gained by phone from David Kennedy of General Chemical in Syracuse, New York, regarding vanadium's role as a catalyst in sulfuric acid. Donald Bleiwas at the Bureau of Mines Minerals Availability Field Office in Denver, Colorado provided information on minerals availability and production cost comparisons.

Within RAND, we thank the RAND library for rapidly obtaining the necessary but scarce reference materials. RAND reviewers William Schwabe and Elwyn Harris provided valuable advice and suggestions. RAND communications analyst David Adamson also provided assistance in restructuring this document. Any remaining errors are, of course, the fault of the authors.
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## GLOSSARY

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<tr>
<th>Term</th>
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<tr>
<td>Abundance</td>
<td>The total crustal abundance of an element is estimated by the total weight of the element in the Earth's crust divided by the total weight of the Earth's crust.</td>
</tr>
<tr>
<td>Beneficiation</td>
<td>A process used to raise the grade of the ore by eliminating unwanted minerals.</td>
</tr>
<tr>
<td>Byproduct</td>
<td>A mineral that can be considered an ore because it can be obtained economically while mining another mineral.</td>
</tr>
<tr>
<td>Concentration</td>
<td>The tendency for the mineral to naturally collect in sufficient amounts to be considered ore.</td>
</tr>
<tr>
<td>Coproduct</td>
<td>Two minerals that are considered ores when mined together but not when mined separately. Coproducts differ from byproducts in that neither mineral could be mined alone at a profit.</td>
</tr>
<tr>
<td>Grade</td>
<td>The quality of the ore, usually defined as the percentage of the desired mineral contained in the ore.</td>
</tr>
<tr>
<td>Ore</td>
<td>Mineral that can be mined at a profit. What is not an ore today may become an ore tomorrow because of changes in the economic environment or changes in technology.</td>
</tr>
<tr>
<td>PGMs</td>
<td>Platinum group metals. The materials considered to be PGMs are iridium, osmium, palladium, platinum, rhodium, and ruthenium. All but osmium are currently considered strategic materials.</td>
</tr>
<tr>
<td>Refining</td>
<td>A process by which metal is recovered from ore.</td>
</tr>
<tr>
<td>Reserves</td>
<td>Deposits that can be productively extracted at the time of determination of the find.</td>
</tr>
<tr>
<td>Resources</td>
<td>Estimated concentration of the element, describing the potential for economic mining. Resources include reserves.</td>
</tr>
</tbody>
</table>
1. INTRODUCTION

PURPOSE

The purpose of this study was to determine the United States’ current and projected (end of the decade) reliance on strategic materials originating from southern African nations.

This single topic also required the consideration of a number of related topics, such as

- How does the United States determine which materials are strategic?
- Which materials do we expect to be on the strategic materials list by the end of the decade?
- What would the impact on U.S. national security interests be of a disruption or cutoff of supplies from southern African nations?
- Are there alternative sources of these strategic materials, and where are they located?
- Can alternative materials be substituted for some of the strategic materials in specific applications?
- How could the United States reduce its dependency on materials originating from southern African nations?

BACKGROUND AND SCOPE

The recent dramatic changes in the world have provided both the opportunity and the necessity to reexamine our strategic interests. In the past, the United States has been dependent on materials obtained from southern and central African nations (Botswana, Lesotho, Mozambique, Namibia, South Africa, Swaziland, Zaire, Zambia, and Zimbabwe). However, most of the documents specifically on the subject date from 1985 and contain data from 1980 to 1982.¹ This Report attempts to reassess U.S. dependence on strategic materials from southern African nations. This subsection will briefly describe which

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¹RAND performed an earlier study for DARPA on strategic minerals used in high temperature engines (Salter et al., 1977); and a more recent study for DARPA on an “insurance” approach to critical defense-related dependencies (Zycher et al., 1991).
nations were included in the study and the key issues (e.g., data availability, alternative sources, and alternative materials).

Nations Examined in This Study

For this study, we define southern African nations as Botswana, Lesotho, Mozambique, Namibia, South Africa, Swaziland, Zambia, and Zimbabwe. Because of its unique material resources, we have also included the central African nation of Zaire. All of the nations considered in this study are shown in bold letters in Figure 1.1. We have also indicated on the map zones particularly rich in selected materials.

These nations have been able to exploit their mineral resources to varying degrees. For example, Mozambique has been engaged in a protracted insurgency that has severely disrupted the production and transportation of minerals in that country. Zaire is undergoing severe political unrest that may lead to a second civil war similar to the one that occurred in the late 1970s, which created a global cobalt crisis. Lesotho’s mineral industry is based primarily on construction stone. The only strategic minerals Swaziland produces are industrial diamond and asbestos, and the country contributes less than 1 percent of world production of each of these minerals. The Republic of South Africa has been a stable supplier of strategic materials for decades. However, there are no guarantees that this country’s transition toward political power-sharing will be peaceful. As a result, there is concern about the ability of South Africa to continue to provide strategic materials to the United States should there be a major political upheaval. In addition, many southern African nations ship their materials over South Africa’s rail lines.

Data Problems Due to Transshipments and Production Source Data

The strategic materials that originate from southern African nations may pass through several hands and several stages of refining before reaching the United States. For example, some of the cobalt imported into the United States originates in Botswana, is shipped to Norway for refining, and then is imported into the United States. (See Section 3 for a detailed discussion of the flow of cobalt into the United States.) Because of these transshipments, it is somewhat difficult to determine the exact U.S. dependence on materials from southern African nations.
Figure 1.1—Southern African Nations Considered in This Study (Shaded)

Legend
Cr Chromium
Co Cobalt
Dm Industrial diamond
Mn Manganese
Pt Platinum group metals
V Vanadium
If each nation published figures on how much it sent to each recipient, one could probably solve the transshipment data problem. However, these data are not available or are sometimes contradictory if available. Even though nations tend to publish data on what they produce, and even what they plan to produce, they do not necessarily publish data on the recipients of their production. For example, the Republic of South Africa does not publish data on the recipients of its exports. Therefore, it is often difficult to track the original source of U.S. imports that come from South Africa via other nations. Since these data are not available for many of the key producers, we cannot be sure exactly what percentage of our strategic materials comes from southern African nations.

**Alternative Sources Issues**

Just because a nation produces or has resources of a specific material does not mean that it is a potential alternative source for that material. The size and quality of the deposit may be insufficient to be economically feasible to develop. For example, the United States has deposits of chromite, the ore from which chromium is refined, but the mines are small or of low grade. As a result, no U.S. chromite mines have been operating to any substantial degree for decades.

Most applications require not only a high grade but also a consistent grade of ore. For example, the U.S. steel industry requires chromium and manganese ores with specific limits on impurity elements. As a result, the steel industry is cautious of using ores that vary widely in grade and that may have different impurities. (See Appendix A for a more detailed discussion of the U.S. steel industry.)

Dependability is also an important consideration. For example, according to a U.S. Bureau of Mines estimate, China has the second-best reserves of vanadium, but internal transportation problems make delivery unreliable.

Finally, certain nations may have a specific material but do not wish to trade with the United States, or vice versa. For example, during the Cold War, the USSR was less likely to provide some of the strategic materials we desire. Conversely, Cuba would like to sell its cobalt and chromite to the United States, but the United States has a trade embargo against Cuba.
Alternative Materials Issues

Some materials may be substituted for other materials, but usually at a substantial increase in cost, a decrease in performance, or both. If the substitute were superior in cost and performance to the strategic material, it would already be the primary material used in that application. Therefore, substitution entails a reduction in performance and an increase in cost.

For example, small amounts of vanadium can significantly strengthen steel. Any of the substitutes (e.g., columbium, manganese, molybdenum, titanium, or tungsten) require larger amounts than vanadium, thereby decreasing the strength-to-weight ratio of the resulting steel. Similarly, the most efficient production of sulfuric acid, an essential chemical for the munitions industry, uses vanadium pentoxide. Alternative production methods using other materials are more expensive and less efficient.

STUDY APPROACH

Because of the constraints on the project, we limited our analysis to information available in the open literature. We started with overall U.S. demand for these materials from southern African nations across all sectors (military, industrial, and civilian) and then examined selected details of dependence in the military sector, rather than starting from a detailed analysis of the military sector for each strategic material.

The analytic approach used in this study was to reduce the list of strategic materials until we determined which southern African materials the United States depends on. The following four steps were applied:

- Start with the list of the 66 strategic materials.
- Reduce the list to only those strategic materials that come from southern African nations.
- Reduce the list further to those materials from southern African nations that produce at least 10 percent of the world's annual production.
- Examine each of these materials for the degree of U.S. dependence and alternative options.
Twenty-two of the strategic materials come from southern African nations. Of these 22 strategic materials, southern African nations produced at least 10 percent of the world’s production in only eight cases. Upon further examination, we found that the United States was not dependent upon three of the eight strategic materials (antimony, industrial diamond, and titanium). These three materials are examined in Appendix B. The remaining five strategic materials (chromium, cobalt, manganese, platinum group metals [PGMs], and vanadium) upon which the United States depends are examined briefly in Section 2 and in detail in Section 3. We also examined the four primary options to hedge against these dependencies, and how they apply to the five remaining strategic materials.

Information was gathered from the Defense National Stockpile Center, the Office of the Assistant Secretary of Defense for Production and Logistics, the U.S. Bureau of Mines, and a standard literature search. We interviewed each of the commodity specialists or their representatives one on one at the U.S. Bureau of Mines and followed up with specific questions by telephone. This research provided essential background on problems with existing data sources, potential alternative sources, and potential alternative materials for each strategic material.

ORGANIZATION OF THE DOCUMENT

Section 2 presents the process of reducing the list of 66 strategic materials to only those five strategic materials from southern African nations upon which the United States is dependent. Section 3 presents the U.S. demand, dependency, and alternatives available for these five strategic materials. Section 4 discusses the options available to hedge against our dependency on strategic materials. The conclusions are presented in Section 5, summarizing the results of this study. Appendix A presents a more detailed discussion of the U.S. steel industry. Appendix B presents the data on antimony, industrial diamond, and titanium from which we concluded that the U.S. is not dependent upon these three materials from southern African sources.
2. U.S. DEPENDENCE ON MATERIALS FROM SOUTHERN AFRICAN NATIONS

This section addresses in order the first five of the six questions raised in the introduction. The first subsection defines strategic materials and dependence. The second subsection projects the demand for these strategic materials across all U.S. sectors (military, industrial, and civilian). The third subsection sequentially reduces the list of strategic materials to be examined in this document. The fourth subsection presents a summary of the U.S. dependence on materials obtained from southern African nations, including a brief discussion of the impact of a disruption of supply, alternative sources, and alternative materials.

DEFINING STRATEGIC MATERIALS AND DEPENDENCE

The Department of Defense (DoD) determines what materials are strategic and critical under statutory guidance in the Strategic and Critical Materials Stockpiling Act (50 U.S.C. 98 et seq.). This act creates a National Defense Stockpile of these materials based on estimated needs in a national emergency. This act also authorizes research and development of substitutes and conservation measures.

Under the act, DoD determines the U.S. dependence on strategic materials in three areas: the requirements of our military ($2.3 billion in January 1991 prices), requirements of the industrial sector ($11 million), and essential civilian needs ($1.0 billion) under mobilization conditions, including civilian austerity measures (DoD, 1992). These demands are then compared to U.S. production of these materials (if any) and to anticipated imports based on foreign production adjusted for projected war damage, shipping losses, reliability of suppliers, and U.S. market share. Materials for which the United States has been found in need are considered strategic and have been authorized by Congress to be included in the National Defense Stockpile. If the strategic materials were not available in sufficient quantities when needed, the ability of the United States to produce essential equipment would be impaired, especially in a time of war.

To hedge against a shortfall in the supply of a given strategic material from traditional sources, the government currently considers four peacetime options:
• Purchasing and stockpiling strategic materials,
• Providing incentives for domestic production of strategic materials,
• Seeking alternative sources of the same materials, and
• Developing alternative materials.

The advantages and disadvantages of each option are presented in Section 4.

The strategic stockpile list currently consists of 66 materials, as shown in Table 2.1. The size of the stockpile for each material is defined as a function of an assumed threat for planning purposes. The planning guidance is based on a statutorily mandated three-year conventional war and a warning period, which is based on intelligence estimates. Although the likelihood of this type of threat has significantly decreased due to the recent world events, the Congress has not altered the three-year–war planning requirement. However, DoD has plans to lengthen the warning period beyond the one year used in recent estimates. In addition, reduced threats have led to reductions in the estimated force structure needed; thus, estimates of stockpile requirements are declining. The implications of these reduced estimates are discussed in Section 4.

PROJECTING DEMAND FOR STRATEGIC MATERIALS

Accurately predicting the demand for strategic materials as of the end of the decade is a very difficult task. Defense-related equipment results from a long series of production steps far removed from the original raw materials. To determine which materials would be in demand for projected military equipment production would require gathering information not only from the major manufacturers, but also from every sub-subcontractor. Unfortunately, information on new trends in the demand for strategic materials is not currently gathered in any single location. The same problem of data availability applies to whether substitutes for current strategic materials would be available and used widely by the end of the decade.

However, the following three factors suggest that the composition of demand for strategic materials will not change significantly by the end of the decade. First, the magnitude of the demand in the military, industrial, and civilian sectors for each strategic material makes it unlikely that the composition of strategic materials will change quickly. For example, the magnitude of steel production in the United States is between 75 and 100 million tons annually, and man-
Table 2.1
The Strategic Materials List (as of 1991)

<table>
<thead>
<tr>
<th>Material</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum metal group</td>
<td>Mica, phlogopite, block</td>
</tr>
<tr>
<td>Aluminum (abrasives)</td>
<td>Mica, phlogopite, split</td>
</tr>
<tr>
<td>Antimony</td>
<td>Molybdenum group</td>
</tr>
<tr>
<td>Asbestos, amosite</td>
<td>Morphine</td>
</tr>
<tr>
<td>Asbestos, chrysotile</td>
<td>Natural insulation fiber</td>
</tr>
<tr>
<td>Bauxite, refractory</td>
<td>Nickel</td>
</tr>
<tr>
<td>Beryllium metal group</td>
<td>PGMs, iridium</td>
</tr>
<tr>
<td>Bismuth</td>
<td>PGMs, palladium</td>
</tr>
<tr>
<td>Cadmium</td>
<td>PGMs, platinum</td>
</tr>
<tr>
<td>Chromite and ferrochromium</td>
<td>PGMs, rhodium</td>
</tr>
<tr>
<td>Chromite, refractory grade</td>
<td>PGMs, ruthenium</td>
</tr>
<tr>
<td>Cobalt</td>
<td>Pyrethrum</td>
</tr>
<tr>
<td>Columbium group</td>
<td>Quartz crystals</td>
</tr>
<tr>
<td>Copper</td>
<td>Quinidine</td>
</tr>
<tr>
<td>Cordage fiber, abaca</td>
<td>Quinine</td>
</tr>
<tr>
<td>Cordage fiber, sisal</td>
<td>Rayon fiber, aerospace grade</td>
</tr>
<tr>
<td>Diamond, industrial</td>
<td>Rheniumic acid</td>
</tr>
<tr>
<td>Fluorospur, acid</td>
<td>Rubber</td>
</tr>
<tr>
<td>Fluorospur, metal</td>
<td>Rutile</td>
</tr>
<tr>
<td>Germanium</td>
<td>Sapphire and ruby</td>
</tr>
<tr>
<td>Graphite, Ceylon</td>
<td>Silicon carbide</td>
</tr>
<tr>
<td>Graphite, Malagasy</td>
<td>Silver, fine</td>
</tr>
<tr>
<td>Graphite, other</td>
<td>Talc, block and lump</td>
</tr>
<tr>
<td>Indium</td>
<td>Tantalum group</td>
</tr>
<tr>
<td>Iodine</td>
<td>Thorium nitrate</td>
</tr>
<tr>
<td>Jewel bearings</td>
<td>Tin</td>
</tr>
<tr>
<td>Lead</td>
<td>Titanium sponge</td>
</tr>
<tr>
<td>Manganese, battery grade</td>
<td>Tungsten group</td>
</tr>
<tr>
<td>Manganese, chemical and metal</td>
<td>Vanadium group</td>
</tr>
<tr>
<td>Mercury</td>
<td>Vegetable extract, chestnut</td>
</tr>
<tr>
<td>Mica, muscovite, block</td>
<td>Vegetable extract, quebracho</td>
</tr>
<tr>
<td>Mica, muscovite, film</td>
<td>Vegetable extract, wattle</td>
</tr>
<tr>
<td>Mica, muscovite, split</td>
<td>Zinc</td>
</tr>
</tbody>
</table>

Ganese is required to produce all of it. Similarly, 1 million tons of stainless steel are produced annually, and chromium is required for all of that. Furthermore, many of the potential substitute materials are only laboratory experiments at the moment. Even if a breakthrough is achieved, it will take years to translate a laboratory process into a production-level technology. So far, the increased use of composites in airframes has not had an apparent impact on the large quantity of steel produced annually in the United States.

Second, some major industries, such as steel, electronics, and super-alloys, have very precise methods of operation, making changes to the process very difficult, time-consuming, and expensive. Third, as the
military’s budget decreases, the demand to produce new types of assets requiring a change in the composition will be significantly smaller than in the past.

These considerations indicate that the composition of the demand for strategic materials imported from southern African nations is not likely to change significantly by the end of the decade.

REDUCING THE LIST OF STRATEGIC MATERIALS TO BE EXAMINED

Obviously, not all strategic materials originate in southern African nations. Therefore, we examined each material entry for the fraction of world production contributed by southern African nations. Only those materials of which these nations provide at least 10 percent of the world’s production were selected for detailed examination in this study (as shown in bold in Table 2.2). Once again, we included the

<table>
<thead>
<tr>
<th>Material</th>
<th>Botswana</th>
<th>Rep. S.A.</th>
<th>Zaire</th>
<th>Zambia</th>
<th>Zimbabwe</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antimony</td>
<td></td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>Asbestos</td>
<td>4</td>
<td></td>
<td>5</td>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beryllium</td>
<td></td>
<td>1</td>
<td></td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cadmium</td>
<td></td>
<td>1</td>
<td></td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chromium</td>
<td>32</td>
<td></td>
<td></td>
<td>5</td>
<td></td>
<td>37</td>
</tr>
<tr>
<td>Cobalt</td>
<td>1</td>
<td>2</td>
<td>58</td>
<td>16</td>
<td></td>
<td>76</td>
</tr>
<tr>
<td>Copper</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td></td>
<td></td>
<td>9</td>
</tr>
<tr>
<td>Diamond</td>
<td>9</td>
<td>10</td>
<td>30</td>
<td></td>
<td></td>
<td>49</td>
</tr>
<tr>
<td>Fluorespar</td>
<td>6</td>
<td></td>
<td></td>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Graphite</td>
<td></td>
<td></td>
<td>2</td>
<td>2</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>Lead</td>
<td>2</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>Manganese</td>
<td>18</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>18</td>
</tr>
<tr>
<td>Mica</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Nickel</td>
<td>3</td>
<td>4</td>
<td></td>
<td>1</td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>PGMs</td>
<td>48</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>48</td>
</tr>
<tr>
<td>Silver</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Tantalum Grp</td>
<td></td>
<td></td>
<td>4</td>
<td>3</td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>Thorium</td>
<td>4</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>Tin</td>
<td>1</td>
<td>1</td>
<td></td>
<td>1</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Titanium</td>
<td>11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>11</td>
</tr>
<tr>
<td>Vanadium</td>
<td>54</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>54</td>
</tr>
<tr>
<td>Zinc</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>3</td>
</tr>
</tbody>
</table>

central African nation of Zaire in this list because of its high production of key strategic materials. Lesotho, Mozambique, Namibia, and Swaziland are not shown, since they produce less than 1 percent of the world's production in any material category. Material productions of less than 1 percent of world production are not shown in the table. Because of round-off errors, not all of the rows sum exactly to the total percentage column.

This 10-percent filter reduced the list to eight materials, which we chose for detailed examination in our study (in alphabetical order): antimony, chromium, cobalt, industrial diamond, manganese, PGMs, titanium, and vanadium. Note that the Republic of South Africa alone produces over 10 percent of the world's production in seven of these eight strategic materials (all except cobalt).

Since percentages do not tell the whole story, Table 2.3 presents the quantities associated with the production of the eight selected strategic materials listed in Table 2.2.

### SUMMARY OF U.S. DEPENDENCE ON MATERIALS FROM SOUTHERN AFRICAN NATIONS

Southern African nations account for 10 percent or more of the world's production of antimony, chromium, cobalt, industrial dia-

### Table 2.3

<table>
<thead>
<tr>
<th>Material</th>
<th>Botswana</th>
<th>Rep. S.A.</th>
<th>Zaire</th>
<th>Zambia</th>
<th>Zimbabwe</th>
<th>Total World Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antimony</td>
<td>6,100</td>
<td></td>
<td>150</td>
<td>61,875</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(metric tons)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chromium</td>
<td>3,800,000</td>
<td></td>
<td>570,000</td>
<td>11,901,300</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(metric tons)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cobalt</td>
<td>275</td>
<td>730</td>
<td>25,000</td>
<td>7,000</td>
<td>90</td>
<td>43,360</td>
</tr>
<tr>
<td>(metric tons)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diamond</td>
<td>4,576</td>
<td>5,106</td>
<td>15,500</td>
<td></td>
<td></td>
<td>51,821</td>
</tr>
<tr>
<td>(1,000 carats)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manganese</td>
<td>1,675,000</td>
<td></td>
<td></td>
<td></td>
<td>9,309,000</td>
<td></td>
</tr>
<tr>
<td>(metric tons)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PGMs</td>
<td>135,800</td>
<td></td>
<td>55</td>
<td></td>
<td>283,643</td>
<td></td>
</tr>
<tr>
<td>(kilograms)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Titanium</td>
<td>652,500</td>
<td></td>
<td></td>
<td></td>
<td>5,801,720</td>
<td></td>
</tr>
<tr>
<td>(short tons)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vanadium</td>
<td>18,200</td>
<td></td>
<td></td>
<td></td>
<td>33,800</td>
<td></td>
</tr>
<tr>
<td>(short tons)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 2.4
**Summary of U.S. Dependence on Selected Materials**

<table>
<thead>
<tr>
<th>Strategic Material</th>
<th>Production Location</th>
<th>Substitute Sources</th>
<th>Produced As</th>
<th>Use or Demand</th>
<th>Recyclable</th>
<th>Substitute Materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chromium</td>
<td>Southern African nations</td>
<td>No&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Main product</td>
<td>Stainless steel&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Not reliably</td>
<td>No</td>
</tr>
<tr>
<td>Cobalt</td>
<td>Central African nations</td>
<td>Yes, but not in sufficient quantities</td>
<td>Byproduct</td>
<td>Alloys&lt;sup&gt;c&lt;/sup&gt;</td>
<td>Yes</td>
<td>Some</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Catalysts</td>
<td>Yes</td>
<td>Some</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Paints&lt;sup&gt;d&lt;/sup&gt;</td>
<td>No</td>
<td>No&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Additives&lt;sup&gt;f&lt;/sup&gt;</td>
<td>No</td>
<td>Some</td>
</tr>
<tr>
<td>Manganese</td>
<td>Widespread</td>
<td>Yes&lt;sup&gt;g&lt;/sup&gt;</td>
<td>Main product</td>
<td>Steel industry</td>
<td>Yes&lt;sup&gt;b&lt;/sup&gt;</td>
<td>No&lt;sup&gt;i&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Alloys</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>PGMs</td>
<td>Widespread</td>
<td>Yes&lt;sup&gt;g&lt;/sup&gt;</td>
<td>Coproduct</td>
<td>Electronics</td>
<td>Yes</td>
<td>No&lt;sup&gt;j&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Byproduct</td>
<td>Catalysts</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Main product</td>
<td>Synthetic fiber production&lt;sup&gt;k&lt;/sup&gt;</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Vanadium</td>
<td>Widespread&lt;sup&gt;l&lt;/sup&gt;</td>
<td>Yes</td>
<td>Coproduct</td>
<td>Steel and titanium alloys</td>
<td>No</td>
<td>Yes&lt;sup&gt;m&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Byproduct</td>
<td>Catalysts</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>
Table 2.4—continued

- The U.S. steel industry requires consistent grades of chromite, which are available only from southern African nations.
- Over one million tons of stainless steel are produced each year, containing an average of 17 percent and a minimum of about 11 percent chromium.
- Cobalt is used as an alloy in superalloys, cemented carbides, and magnets.
- Cobalt is used both as a pigment and as a drying agent for paints.
- Cobalt does not show up well on infrared sensors and, therefore, is used in camouflage paints.
- Cobalt bonds organics to metals, such as in the production of belted tires.
- One of the most economical concentrations is in South Africa.
- The steel industry recycles manganese as an incidental component of steel scrap.
- For economic and metallurgical reasons, the U.S. steel industry requires consistent grades of manganese to produce 75 to 100 million tons of steel annually.
- Gold may be used as a substitute but is very expensive.
- Palladium is required in spinningets that produce high-quality carbon fiber.
- Vanadium is distributed worldwide but at low concentrations.
- Vanadium substitutes do not have as good a strength-to-weight factor. There is no substitute for vanadium as a titanium alloying agent.
- Vanadium is a key catalyst in the production of sulfuric acid, which is used heavily in chemical and munitions production industries.
mond, manganese, PGMs, titanium, and vanadium. Three of these materials (antimony, industrial diamond, and titanium) can be readily obtained from other sources. The remaining five are produced most economically by southern African nations.

The United States is currently very dependent on two strategic materials (chromium and cobalt), and somewhat dependent on three other strategic materials (manganese, vanadium, and the PGMs) that are obtained from central and southern African nations (see Table 2.4).

Two reasons underlie this dependence. The first is that the U.S. steel industry depends heavily on consistent grades of chromium and manganese with few unknown impurities. The automated processes involved in the mass production of steel are optimized around a narrow range of consistent grades of these two materials. Any variation in the consistency and purity of these materials could be devastating to the existing domestic steel production processes. (See Appendix A for a more detailed discussion of the U.S. steel industry.)

The second reason for U.S. dependence on these materials is that the most economical deposits of cobalt, vanadium, and PGMs lie in central and southern African nations. Not only do large deposits exist in these countries, but the materials can be produced as coproducts and byproducts, which are much more efficient to mine together than separately. Any alternatives to producing these three materials would be very expensive and not competitive in comparison.

For example, alternative sources of cobalt are available around the world, but contribute less than 25 percent of the current world production of cobalt. If the flow of cobalt from southern African nations were completely cut off, the remaining world production of cobalt could not meet existing demand for cobalt.

The next section presents a more-detailed examination of the five strategic materials from southern African nations upon which the United States is currently dependent. If this level of detail is not of interest, the reader may skip to the following section on hedging against dependency.

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1 The production rates of the byproducts and coproducts also depend on the economics of the primary mineral and the coproduct mineral, respectively. For example, cobalt is produced in various countries as a byproduct of nickel, copper, zinc, and PGMs. Vanadium has been produced as a byproduct of uranium and titanium and by processing waste petroleum coke, iron slag, and fly-ash (the material that collects at the top of smokestacks). PGMs are often produced as a byproduct of copper.
3. DEMAND, DEPENDENCY, AND ALTERNATIVES BY SELECTED MATERIAL

This section presents the results of our investigation of the five strategic materials (chromium, cobalt, manganese, PGMs, and vanadium) upon which the United States is currently dependent. For each material, we describe the demand or uses by type and quantity, production location and methods, possible substitute sources including recycling, options for alternative materials, and the overall degree of U.S. dependence on each material.

CHROMIUM

Demand for or Use of Chromium by Type and Quantity

The primary use of chromium is in the production of stainless steel. Chromium is used to make ferrochromium alloy, which in turn is used to make steel alloys. The U.S. steel industry demands consistent grades of ore to produce 1 million tons of stainless steel per year, which has an average of 17 percent chromium and a minimum of about 11 percent chromium.

The demand for chromium in the United States is closely related to the U.S. steel and chemical industries, which together accounted for 92 percent of U.S. chromite consumption. Another 8 percent was consumed in the production of refractories. For chromium ferroalloys and metals, stainless steel and heat-resisting steel consume 78 percent of our chromium supply, full-alloy steel consumes another 9 percent, high-strength low-alloy and electrical steels consume 3 percent, super alloys another 3 percent, and 7 percent is consumed in other end uses (see Figure 3.1).

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Chromium is used in several direct defense applications. Many military equipment items must be manufactured of stainless steel, including tools, fasteners, and bolts; superalloys containing 5–10 percent chromium are used in jet engines; gun barrels are chrome-plated for longer life; zinc-chromium paint is used on helicopters to meet military specifications on oxidation resistance; and chromium green pigment is used for camouflage.

Indirect defense applications include the chemical industry, which needs stainless-steel pipes and tanks for corrosion resistance. The military depends on the chemical industry for fuels and munitions. The modern military also depends heavily on the electronics industry, which depends on chromium for hardware, manufacturing tools, etc.

Ten percent of the stainless steel made in the United States goes into direct military applications. The end uses of 50 percent of stainless steel are not tracked, so the indirect influence on the military may be higher. For example, medical, hospital, and kitchen equipment all require stainless steel, adding to the military's dependence on chromium.
Technological changes are likely to increase the use of chromium as an alloying agent. Demand for chromium shows steady long-term growth of about 3 percent annually (over the business cycle of 7–10 years) in the United States and worldwide.2

Production Locations and Methods for Chromium

Regular U.S. domestic chromite mining ceased in 1961. In 1990, the United States imported 321,000 metric tons of chromium, nearly two thirds of which originated in Africa (54 percent from the Republic of South Africa, and another 10 percent from Zimbabwe).

The United States, Europe, and Japan make stainless steel but are not ore producers. The ore-producing nations are moving toward vertical integration by building ferrochromium production plants.3 Ferrochromium production started shifting from industrial countries to producer nations around 1970. South Africa will soon begin stainless steel production. Zimbabwe has maintained a policy of exporting only processed ferrochromium; this policy may be modified, however, to allow sales of refractory chromite.

Possible Substitute Sources for Chromium

World resources exceed 11 billion tons of shipping-grade chromite, and 95 percent of this reserve base lies in southern Africa. Nearly all chromium deposits are located in southern Africa or the former USSR, and the latter uses most of its production to meet domestic needs.

South Africa is the largest market-economy producer, while the Soviet Union is the largest centrally planned–economy producer. Each has one-third of current world production, while the remainder is split among many small producers. For example, the United States also imports from other nations (Turkey, 15 percent; Yugoslavia, 5 percent; and other nations, 16 percent), but the grades are less consistent from these sources. If South Africa were no longer a

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2Refractory (high-temperature resistant) chromite is used to make brick molds or for casting, but technical advances have brought on a decline in its use. This is due to the decline of open-hearth refineries; alternative processes do not use chromite refractories.

3Vertical integration in this case means that those nations that produce the raw ore are also choosing to further process the ore themselves before selling it to consumers, thereby obtaining the profits from the value added to the refined product. They are integrating control over sequential steps in the production process.
source, every other market producer would have to double production, which would be virtually impossible.

Furthermore, the grade and consistency of chromite ore are significant factors in the steel industry. Chromite ores from nations other than South Africa are not necessarily of lower grade but have different types and amounts of impurities. Since steel manufacturing is a process of removing some elements and adding others to iron to gain the desired properties in the finished steel, any changes in the ingredients necessitate changes in the production process. The steel production process in the United States is highly automated and not very forgiving when unknown levels of impurities are entered into the batch. Therefore, ferrochromium and steel producers fear contaminating their batches or equipment with impurities from unknown or different sources of ore.

We estimate that over 50 percent of the U.S. supply of chromium originates from South Africa, though obtaining an exact tally of transshipper
cers and reexporters is difficult. South Africa does not publish export figures by country. At the U.S. Bureau of Mines, the International Data Division usually obtains this information from the materials officers at their respective Embassies. Some countries, like Japan, are very open about where they get their supplies of raw materials, but others are not so forward. A major problem with finding information about chromium is that it is not the most important commodity in each of the producer countries, so it is often given little statistical importance by the minerals officers charged with collecting and transmitting this information.

Chromium is also produced from stainless steel scrap, and this substitutes for ferrochromium. Approximately 88,000 metric tons of chromium were produced from scrap in 1990, which accounted for 21 percent of chromium demand. Recycled stainless steel is not used to produce ferrochromium, but is used as secondary or scrap metal.

Options for Alternative Materials for Chromium

There are no adequate substitute materials for chromite ore in the production of ferrochromium, certain chemical compounds, or chromite refractories. There is no substitute for chromium in stainless steel or in chromium-containing superalloys.

Nickel-based alloy substitutes can be found for some applications, but at a substantial increase in cost and a decrease in performance.
Replacement by alternative materials for chromium-containing products could significantly reduce U.S. consumption of chromium. For example, a toaster need not be chromium-plated to be functional. If the United States made an effort to reduce chromium consumption over the next five to ten years, we could achieve an estimated 60 percent reduction in the use of chromium in metal alloys, a 15 percent reduction in the use of chromium for chemicals, and a 90 percent reduction of the chromium used in refractories.

Overall Degree of U.S. Dependence on Chromium from These Nations

The United States is very dependent on chromium from southern African nations. As noted above, there are no reasonable substitutes for chromium, and world production would not be able to compensate for a shortfall if the southern African sources were shut down. Potential U.S. production sites are either of low grade or small deposit size, and the return is not good enough for investment. There is some recovery of chromium from scrap (not counting "home scrap" that is recycled at the plant where it is produced), but this does not constitute an adequate or reliable source for military supply. Therefore, we are dependent on foreign sources for our chromium and are vulnerable to disruptions in the supply. This dependency on chromium can be reduced somewhat by using substitute materials for applications that do not require chromium.

The stockpile status for ferrochromium exceeds the goals, while the stockpile for chromite ore is at only about half of the goal.

COBALT 4

Demand or Use of Cobalt by Type and Quantity

Approximately 40 percent of the cobalt consumed in the United States goes into "superalloys" used to make industrial and aircraft turbine engines. These alloys are also used for medical prosthetics. About 10 percent is consumed in permanent magnets (e.g., AlNiCo magnets and samarium-cobalt magnets) used in motors and electronics. Magnets that include cobalt generally resist corrosion and high temperatures better than normal magnets. Another 10 percent is used as a catalyst by the petroleum and chemical industries. Ten percent of

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the cobalt is used as a catalyst for drying paint and ink. Ten percent of the cobalt is used in cutting and wear-resistant materials, such as cemented carbide inserts for metal-cutting. (A cobalt matrix binds tungsten carbide particles or industrial diamonds.) The remaining 20 percent goes to other uses, including pigments, tool steels, and bonding enamels or rubber to metals. Cobalt is used in the production of belted tires as a bonding agent between the brass-covered steel belts and the tire rubber. It is estimated that the United States will consume 7,850 tons of cobalt in 1991 (see Figure 3.2).

The most significant direct defense uses of cobalt are in superalloys used in military jet engines and in camouflage paints, because cobalt pigments are not easily detected by infrared illumination. The numerous indirect defense applications include industrial tools that make armaments and turbines that produce electricity for the production process. Cobalt magnets are superior to other types because they retain their magnetic properties at high temperatures.

Production Locations and Methods for Cobalt

Cobalt is a byproduct of nickel, copper, zinc, or PGM production. As a result, it is only economical to produce in conjunction with another

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**Figure 3.2—1989 Cobalt Consumption and Sources**

SOURCES: 
material as the main product.\textsuperscript{5} The lowest-cost significant deposits of cobalt for production as a byproduct exist in southern Africa.

The United States does not mine or refine cobalt. At least 60 percent of the cobalt imported to the United States comes from the central and southern African nations of Zaire, Zambia, and Botswana. This percentage includes cobalt from Zaire that is processed in Belgium and cobalt from Botswana that is refined in Norway.

**Possible Substitute Sources of Cobalt**

World cobalt resources are estimated to be 11 million tons, but the most economical deposits lie in Zaire and Zambia. The United States' estimated resources are 1.3 million tons, but these are not economical, nor are they likely to be economical in the foreseeable future.

The United States imports cobalt from the following nations: Zaire, 28 percent; Zambia, 25 percent; Canada, 20 percent (some of which comes from Australia); Norway, 13 percent (which originated in Canada, Botswana, or the USSR); and other nations, 13 percent (see Figure 3.3).

It is not feasible for the United States to shift its imports of cobalt from central and southern African nations, as the rest of world production is too low to compensate for current levels of U.S. demands. There is also a quality consideration. For example, cobalt from the former USSR is of lower quality.

Cobalt is not recyclable except in alloy form or as catalysts. In 1990, 1,225 tons of cobalt were recycled from various materials, including superalloys, cemented carbide scrap, and discarded magnets. Recycled cobalt satisfied 16 percent of the nation's consumption of cobalt in 1990.

**Options for Alternative Materials for Cobalt**

There are no substitutes for cobalt in most of its current uses. Research has focused on reducing the amount of cobalt in some alloys. For example, nickel has been found to be an adequate substitute in superalloys, but at some increased cost and sacrifice in performance. Work is also continuing on ceramic substitutes for superalloy applications, but these will not displace cobalt in the near future. In other

\textsuperscript{5}Only Morocco produces cobalt as a main product.
Figure 3.3—Cobalt Sources, Transshipments, and U.S. Imports

Applications, nickel may be substituted, but also at a loss of performance. For magnets, nickel, platinum, barium or strontium ferrite, and iron could be used as substitutes. In machinery, nickel, tungsten, molybdenum carbide, and ceramics could be used. In jet engines, nickel and ceramics could be used. Nickel could be used as a substitute for cobalt in catalysts. In paints, copper, chromium, and manganese could be used as substitutes.⁶

⁶Note that many of the substitutes listed already appear on the list of strategic minerals. Therefore, if there were a shortage of strategic minerals in general, many of these substitutes could be as unavailable as cobalt, depending upon the cause and location of the shortages.
Overall Degree of U.S. Dependence on Cobalt from These Nations

The United States is very dependent on cobalt from central and southern African nations. The "cobalt crisis" in the late 1970s gave some indication of the industrial nations' dependence on central and southern African cobalt production. Planes were sent into Zaire to obtain some of the cobalt, and prices climbed because of the fear that the supply of cobalt would be significantly reduced. However, it turns out that Zaire produced more cobalt that year than in previous years.

Since this crisis, some extraneous uses for cobalt have been curtailed. However, new applications for cobalt were developed during the period of market stability in the 1980s. Over the past few years, demand has exceeded production, so the stocks of cobalt built during the crisis have been drawn down. Any future disruption in supply may have a serious effect on defense manufacturing, given our reliance on cobalt alloys to meet high defense specifications and on cobalt in tools used in arms manufacturing. If all of Zaire's cobalt production were shut down (over one-third of the world's production), the rest of the world's production could not satisfy the current world demand for cobalt.

Much of the cobalt in the strategic stockpile is of lower quality than is suitable for superalloy and other critical applications and is currently in need of upgrading. The U.S. stockpile goal is 77,474,000 pounds, but only 47,880,000 pounds were stockpiled (about 62 percent of the goal) as of 1990. Another 372,000 pounds have passed inspection and are available to the stockpile pending completion of the payment paperwork.

MANGANESE

Demand or Use of Manganese by Type and Quantity

Manganese is an essential element in the production of steel. The U.S. steel process depends heavily on specific and consistent grades of ferromanganese alloy to produce between 75 and 100 million tons of steel annually. The manganese content in steel typically ranges from 0.2 to 2.0 percent.

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2Of the 75 to 100 million tons, nearly 2 percent is stainless, 10 percent is alloy, and the rest is carbon steel.
There are three groups of ferromanganese, based on their carbon content: high, medium, and low. The lower the carbon content, the higher the cost. Medium- and low-carbon ferromanganese are used mostly in the production of stainless steels with relatively low carbon content, which requires more demanding production criteria than ordinary stainless steel.

Silicomanganese is also used in the U.S. steel industry, primarily in the minimills.\(^9\) Silicomanganese has a medium carbon content, and the silicon in silicomanganese acts as a strong deoxidizer in the steel batch. Manganese is added to keep the oxides and other impurities from forming pockets while working the hot metal, thereby helping to avoid weak points in the produced steel.

Manganese is also used in steel to control sulfur, a common impurity in steel. A 20:1 ratio of manganese to sulfur will essentially "tie up" the sulfur and render it harmless.

Hadfield steel (13 percent manganese) has a high resistance to wear and abrasion. It is used in superstrong crushing surfaces and in railroad switches.

Although manganese is used primarily in the steel and metals industries, there are other uses for manganese. Although pure manganese metal is very brittle and not useful as a structural material, manganese metal is an important alloying element in the production of aluminum cans. Manganese is also used in dry cell batteries, plant fertilizers, and animal feed and as a colorant for bricks. United States consumption of manganese is estimated to be 725,000 tons in 1991. The manganese consumed in 1990 cost $450 million (see Figure 3.4).

Although there are few direct military applications for manganese, it is essential to steelmaking and therefore to the production of armaments. One example of a more direct application of manganese is as a component in a specialized battery used by the U.S. Army Signal Corps.

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\(^9\)The U.S. steel industry has two parts: "integrated" producers, which mine the ore, make iron using blast furnaces, then refine the crude iron into steel, and "minimills," which process steel scrap to produce steel. Minimills rely on scrap, and have grown at the expense of integrated producers. For economic and technical reasons, minimills prefer to use silicomanganese to add silicon and manganese.
Production Locations and Methods for Manganese

Manganese is distributed widely around the globe. However, the grade of manganese varies widely by location. Commercial grades of manganese typically range from 35 percent to 54 percent for ore and 74 percent to 95 percent for ferromanganese. Only low-grade (<35 percent) manganese is produced in the United States because of a lack of high-grade sources of manganese, and this accounts for less than 1 percent of consumption. The U.S. steel industry prefers consistent, as well as high, grades of ferromanganese. Ferromanganese from South Africa fulfills these conditions.¹⁰ Certain ores from South Africa are particularly desired because of their low phosphorous content, since high concentrations of phosphorous make the steel brittle. From 1986 to 1989, the Republic of South Africa produced 38 percent of all ferromanganese imported into this country and 28 percent of all U.S. manganese direct imports. Much of the manganese metal used in beverage cans also comes from South Africa.

¹⁰South Africa owns a ferroalloy plant in Rockwood, Tennessee (near Knoxville), but this facility is not currently producing any material. It was purchased from Union Carbide, which had been a producer of ferroalloy until the steel industry entered its long slump in the early 1980s. It was renovated for about $50 million, but because of the continued slump in the steel industry and the long period of inactivity (since 1982), it will probably not return to production.
South Africa contains 45 percent of the world's manganese reserves, while the former USSR contains 36 percent of the world's reserves as of 1990. The Republic of South Africa contains 80 percent of the world's resources of manganese outside of the former USSR and China (not counting manganese nodules on the ocean floor and other underwater sources of manganese). As an ore producer, South Africa is unique in producing low phosphorous ore, which is required for some applications, such as Hadfield steel.

Making ferroalloys is very energy intensive. As a result, some nations, such as Japan, are phasing out silicomanganese production, which uses more energy than producing equivalent amounts of ferromanganese.

Possible Substitute Sources for Manganese

Manganese as an element is spread around the world, but there are relatively few sites that are sufficiently concentrated to be economically and profitably mined. Economical mining operations exist, mainly one company each in Australia, Brazil, and Gabon and two companies in South Africa. India has a large number of small operations, but produces low quality manganese.

The former Soviet Union produces a large amount of ore, primarily in the Ukraine and Georgia, but it is also of low grade (averaging less than 30 percent manganese and high in phosphorous). As a result, the Soviets have been a net importer of high-grade manganese ore in recent years.

China also produces manganese from numerous low-grade mines and imports high-grade manganese to improve its smelting operations so that manganese ferroalloys can be exported at a profit.

Total U.S. direct imports of manganese from 1986 to 1989 are as follows: Republic of South Africa, 28 percent; France, 14 percent; Gabon, 13 percent; and other nations, 45 percent. Manganese is recycled in the U.S. steel industry, but only incidentally as a component of steel scrap.

Although it is not economically feasible at this time, manganese and other metals could be “mined” from nodules found on the ocean floor at a depth of about 15,000 feet. However, there are technological problems involved in exploiting this resource, as well as legal prob-

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11The supply from Gabon may be somewhat vulnerable, as ore shipments are made by tramways and rail lines that can be easily disabled.
lems where the Law of the Sea applies. As an alternative, the U.S. Bureau of Mines is exploring the possibility of "mining" crusts (submerged islands) under the sea near Hawaii. This option would avoid some technological problems and territorial disputes, since the crusts lie in only 5,000 feet of water, within U.S. territorial waters.

**Options for Alternative Materials for Manganese**

Although some substitutes are available for manganese in certain alloys, no reasonable substitutes exist for manganese used in steel production. Since all of the components in a batch must work together to give steel its properties, any substitute for manganese in steel production will alter the nature of the final product. There are no one-to-one substitutes for manganese, and therefore any substitution would necessitate juggling the other elements to achieve the desired results. As long as the United States produces steel, it will require manganese.

There are two ways in which the steel industry could reduce its consumption of manganese. The first is that aluminum and zirconium could be substituted for manganese as the deoxidizers. The second is that the steel industry could use low-sulfur iron ore, resulting in a lower manganese requirement. Either alternative increases cost.

**Overall Degree of U.S. Dependence on Manganese from These Nations**

The U.S. steel industry is currently dependent upon the consistency of affordable manganese ore from southern African nations. However, it would be difficult to imagine a situation in which the United States could not import any manganese, given its worldwide availability. If southern African nations no longer produced the ore, the United States could adapt to other sources at an increased cost. However, Japan and Europe (except for France, which gets its ore from Gabon) are much more dependent on manganese ore from southern African nations. As a result, our potential allies in a future conflict may be more affected than the United States by a cutoff of manganese from southern African nations.

The United States' national stockpile averaged 67 percent of the goal in metallurgical ore, while the stockpile exceeded the goals in most other categories of manganese (such as ferromanganese).
PGMs

Demand or Use of PGMs by Type and Quantity

PGMs include iridium, osmium, palladium, platinum, rhodium, and ruthenium. All but osmium are considered strategic materials. Some of these metals are uniquely suited for specific tasks. For example, platinum, palladium, and rhodium are used in automobile catalytic converters, which account for approximately 35 percent of U.S. PGM consumption. Palladium has many uses in electronics and is often used in combination with gold and silver in contacts and conductors. About 32 percent of PGMs is used in electronics. Dental and medical uses consume 9 percent. PGMs are also used as catalysts in chemical reactions, accounting for 6 percent of U.S. consumption. About 18 percent of PGMs is consumed in other applications. For example, PGMs are used as bushings and spinnerets for producing glass and carbon-fiber threads and other advanced materials. The United States spent $635 million on PGMs in 1990 (see Figure 3.5).

Defense applications of PGMs are numerous, especially in advanced electronics. While contacts made of copper or aluminum quickly tarnish and lose their efficiency, contacts of PGMs tarnish very slowly, if

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Figure 3.5—1989 PGM Consumption and Sources

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at all. Clean contacts are especially important in electronic components where reliability is essential in spite of long periods of dormancy, such as in intercontinental ballistic missiles.

PGMs also contribute indirectly to defense via their use in producing advanced materials. As advanced materials gain increasing importance in military aerospace applications, the production of high-quality glass, rayon, carbon, and other fibers becomes more crucial.

Advanced carbon-fiber production requires very smooth wear-resistant and corrosion-resistant surfaces on spinnerets and bushings, which can be provided only by PGMs.

Production Locations and Methods for PGMs

PGMs are widely distributed around the globe, but the lowest-cost significant concentrations appear to be in the former USSR and the Republic of South Africa. The advantage southern African nations hold is that they have large deposits of PGMs and produce them as coproducts and byproducts, making them the most economically efficient sources. The United States imports 46 percent of its PGMs from the Republic of South Africa.

Any alternative location for mining PGMs will take time and money to discover, identify, and start new mines. Unfortunately, there is a long lead time between identifying the needs and starting up a new mine, as is the case with most mined commodities. Since the PGM mines in southern African nations are so economical, starting such mines simply as insurance against the disruption of PGMs would not be cost-effective.

Possible Substitute Sources for PGMs

Approximately 93 percent of the world’s production of PGMs is mined either in the former USSR or the Republic of South Africa. In addition, 89 percent of the world’s reserves of PGMs resides in South Africa. Less than 1 percent of the world’s reserves of PGMs is in the United States. However, approximately 9 percent of the world’s resources of PGMs lies in the United States (9 million of 100 million kilograms).

In addition to the 46 percent from South Africa, the United States also imports PGMs from the following nations: the United Kingdom, 17 percent; former USSR, 10 percent; and other countries, 27 percent. However, most of the PGMs that we import from countries outside of South Africa actually originated from South Africa.
Given the nature of PGMs and their use in electronics and as catalysts, they are amenable to recovery from scrap. New firms have been formed to recycle precious metals from expired catalytic converters and discarded electronics, and this process will accelerate if prices increase. These secondary sources have been dubbed "above-ground mines."

In 1989, recycling in the United States produced 5,300 kilograms on a nontoll basis. The toll basis of recycling produced about 63,000 kilograms. Another 17,000 kilograms (worth $184 million and providing 50% of our export) of PGM contained in waste and scrap was exported from the United States to be recycled in the United Kingdom, the Federal Republic of Germany, Italy, and other countries.

Options for Alternative Materials for PGMs

There are no alternatives for PGMs, except for gold. Gold can substitute for the palladium-and-silver alloy used in contacts in electronics, but at increased cost. Given the high cost of PGMs, there are ongoing efforts to find suitable catalytic alternatives, but none have been identified to date. Alternatives for platinum are under investigation.

Overall Degree of U.S. Dependence on PGMs from These Nations

The United States is somewhat dependent on southern African nations for PGMs. However, alternative sources exist worldwide, and even within the United States. Right now, and in the foreseeable future, southern African nations have the most economical deposits of PGMs because they are produced as coproducts and byproducts. Furthermore, disruption of PGM imports from southern African nations puts the United States at risk, because no other countries produce appreciable amounts of these materials.

As a result, we will likely continue to be dependent on South Africa for PGMs, even if we increase the level of imports from other nations, such as the former Soviet Union.

\[13\] A "toll" is a charge paid to a refiner for recycling material for the producer, such as refining a catalyst for continued use. "Nontoll" is scrap that is sold to a refinery for extraction and later resale. Nontoll PGMs are included in the supply calculations, while toll PGMs are not.

\[14\] In Australia, a large reserve of PGMs and gold was recently found at Coronation Hill. However, this deposit is not being developed because of the concern of the Australian natives at that site.
The current U.S. stockpile status is lower than our goals, because of the high cost of these materials. There are no inventories of rhodium and ruthenium, despite stockpile goals for these two metals.

**VANADIUM**

**Demand or Use of Vanadium by Type and Quantity**

Eighty-five percent of U.S. vanadium consumption is used for creating "high-strength/low-alloy" and other steel alloys, which are used in applications where a high strength-to-weight ratio is needed, such as bridges, automobiles, and small appliances. Three percent of the vanadium is used as a catalyst in the production of sulfuric acid, maleic anhydride, and other chemicals. Vanadium is also alloyed with titanium for added strength in aerospace applications.

Vanadium is consumed in the following end products: machinery and tools, 34 percent; transportation, 23 percent; building and heavy construction, 18 percent; and other applications, 25 percent (see Figure 3.6).

**Figure 3.6—1989 Vanadium Consumption and Sources**

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Direct defense applications of vanadium include aerospace materials and high-strength steels. In aerospace applications, very small amounts of vanadium added to titanium and steel greatly increase the strength of the alloys. Vanadium is also used to produce high-strength armor plating for military vehicles and is sometimes a component in batteries.

Indirect defense applications include using vanadium pentoxide in the production of sulfuric acid, which is essential in the production of munitions. Vanadium pentoxide is much more efficient and less expensive than the old lead-chamber process used to create sulfuric acid.

Production Locations and Methods for Vanadium

Vanadium is distributed widely around the globe, but in very low concentrations. The most economical concentrations of vanadium occur in southern African nations, where vanadium is produced as a coproduct or byproduct.

Two-thirds of U.S. vanadium production is for domestic consumption. The United States imports 37 percent of its vanadium from the Republic of South Africa. The Republic of South Africa produced 51 percent of the world’s production of vanadium in 1990.

Possible Substitute Sources for Vanadium

The United States imports vanadium from the following regions: South Africa, 37 percent; European Community, 31 percent (much of which originates in South Africa); South America and Mexico, 14 percent; Canada, 7 percent; and from other regions, 11 percent.

The world reserve base of vanadium exceeds 140 billion pounds (70 million tons) but in low concentration (less than 2 percent of host rock). High-quality vanadium ore is between 1.5 percent and 2 percent vanadium. China has the second most economical natural concentration of vanadium after South Africa, but China is an unreliable source because of internal transportation problems. Australia claims a new find that equals South African ore in quality.

The United States has some natural sources of vanadium, such as Hot Springs, Arkansas, but these are of low grade (less than 1 percent). The United States produces vanadium from different sources. For example, the Monsanto company produces a ferrophosphorus slag, from which the Kerr-McGee company extracts vanadium. Iron slag and fly-ash (the material collected at the top of smokestacks of
iron and steel plants) are imported from overseas and processed for vanadium, although this is considered domestic production.

Some vanadium is recycled from tool-steel scrap, scrap iron, iron-ore slag, and steel alloys. However, vanadium concentrations are also low in these sources. Vanadium is also recovered from petroleum refining residues, fly-ash, and spent catalysts.

**Options for Alternative Materials for Vanadium**

The price of vanadium has been as high as $11 per pound, while in 1990 it was as low as $2 per pound. As is the case with most substitutes, any of the current substitutes are of higher price and lower performance than vanadium.

Such materials as columbium, manganese, molybdenum, titanium, and tungsten may be substituted for vanadium in steel alloys, but at a loss of performance. For example, columbium is a viable substitute only in thin sheet applications (less than 2 inches thick). Vanadium provides the best strength-to-weight ratio, because of the small amounts of vanadium required to provide significant increases in strength.

There are no adequate substitutes for vanadium as an alloy for titanium in aerospace applications. There are also no economical substitutes for vanadium pentoxide in the production of sulfuric acid. The old lead chamber method of producing sulfuric acid was very inefficient compared to vanadium pentoxide. In other chemical processes, platinum and nickel can replace vanadium compounds, but at a much higher cost.

**Overall Degree of U.S. Dependence on Vanadium from These Nations**

The United States does appear to be dependent on vanadium, but not necessarily dependent on vanadium provided by southern African nations, since vanadium is widely distributed around the world. However, the most economical sources of vanadium are in the southern African nations, and therefore they will tend to dominate the market in the foreseeable future. The national stockpile of vanadium was well below the 1990 goals.
4. HEDGING AGAINST DEPENDENCE

This section discusses four options for hedging against U.S. dependencies on strategic materials: purchasing and stockpiling strategic materials, providing incentives to continue existing domestic capabilities, funding research into alternative sources for the strategic materials, and funding research into alternative or substitute materials. Recycling efforts are included under the alternative sources option, while conservation, replacement, and substitution efforts are included under the alternative materials option. The advantages and disadvantages of each option are presented in each subsection. The last subsection attempts to answer the final question raised in Section 1 by discussing the current applicability of each of these hedging options to the five selected strategic materials.

PURCHASING AND STOCKPILING STRATEGIC MATERIALS

DoD's recommended stockpile goals were based on a statutorily mandated three-year war with a one-year warning time based on intelligence estimates. Changes in the world situation have made it hard to envision a scenario in which a three-year protracted war could occur. Even with the current guidance on preparing to meet two simultaneous contingencies, it would be hard to consider both contingencies lasting for three years while requiring a level of production that could consume the current stockpile.

It is also difficult to imagine the types of arrangements leading to a cartel, such as OPEC, forming with respect to selected strategic materials. Although many different material cartels have been discussed since OPEC first formed, no successful OPEC-like material cartels have actually been formed.

The most likely threats to the nation at the moment are unintentional economic shocks that temporarily affect the availability and drive up the cost of selected strategic materials. The current political unrest in Zaire may erupt in civil war, which could lead to a cobalt crisis similar to the one that occurred in the late 1970s.

The advantages of stockpiling include the increased ability to withstand short-term shocks and longer-term shortages (up to the amounts stockpiled), more time to expand alternative sources and alternative materials production, and less reliance on potentially vulnerable overseas trade routes.
The disadvantages of stockpiling include the costs of buying, protecting, further refining, and transporting stockpile materials. Raw ore takes up more space and incurs higher storage costs, but refining the ore is more expensive than storing the raw ore for most strategic materials. A program to upgrade the stockpile was initiated to refine selected strategic materials so that they could be in a more useful form. For example, stockpiled chromium ore is being upgraded to ferrochromium because of a presidential mandate and a congressionally required program begun in 1982.

Furthermore, even though the demand for the raw material may be relatively stable, the required form, grade, or purity of the material may change rapidly, depending on the application. For example, one could refine a material to meet the current specifications in a given industry. If, however, that industry is changing rapidly (e.g., the electronics industry), the refined material may not meet the new specifications in a few years. Since material specifications can change quickly, what is refined and stockpiled now may be useless when it is needed.

Another concern is that even if we stockpile the raw materials, we may not have the domestic refining capability necessary to produce the intermediate form of the material. For example, the United States no longer has the capability to produce sufficient ferromanganese from manganese ore to meet the domestic demand. If we were to import manganese, we would either have to expand our current capability to produce ferromanganese or have to ship it to someone who can produce ferromanganese for us, thereby increasing the risks involved in overseas transport.

There are also few precedents in stockpiling strategic materials. France, Japan, the United Kingdom, Sweden, and South Korea appear to be the only other nations in the free world to stockpile materials, and even they have stockpiled fewer materials in smaller amounts. It appears that the United States may be one of the few nations that can afford to stockpile large quantities of strategic materials, and other nations may depend on us to provide that buffer in case of economic shock.

A strategic stockpile can be useful as a buffer in absorbing shocks. If not handled carefully, however, such a stockpile can create its own shocks. For example, between 1965 and 1968, the United States sold off a substantial portion of the copper in the strategic stockpile. The result so depressed the price of copper as to harm both the domestic and foreign copper industries significantly. Any reduction in excess stock-pile, which we now have in many materials because of the
changing international political environment, must be sold off slowly enough so as to not damage domestic and friendly foreign mining operations.

A final concern regarding the creation of unintentional shocks by selling part of the stockpile is that even the mere announcement of the intention to sell selected materials tends to wreak havoc on the price of that commodity in the world market. Care must be taken to minimize these unintentional shocks while attempting to reduce excess materials in the strategic stockpile.

PROVIDING INCENTIVES FOR DOMESTIC INDUSTRY

Since domestic capabilities to produce or process raw forms of strategic materials have continued to decrease over the years, stockpiling is one way to compensate for this trend. However, a second alternative is to provide incentives to domestic industry to maintain a strategic capability.

For example, aerospace-grade rayon was added to the stockpile requirements about three years ago, since the sole U.S. source was shutting down. DoD purchases, as part of regular weapons-related procurement programs, allowed production to continue until a domestic buyer was found for the company who would maintain rayon production for the foreseeable future.

The advantage of this option is that it attempts to enable an already existing domestic operation to continue to provide the strategic materials desired.

The disadvantages of this option are that it continues the depletion of domestic resources and that the subsidized operation may operate at a loss for the foreseeable future. This may or may not be at a higher ongoing cost than stockpiling. In addition, this option only applies to cases in which an existing domestic capability exists, which is not the case for most of our strategic materials.

FUNDING RESEARCH INTO ALTERNATIVE SOURCES OF STRATEGIC MATERIALS

The third alternative is to fund research into alternative sources of the same material. An example of such research is the development of undersea manganese sources. Undersea sources of manganese include both deep sea nodules and crusts (e.g., submerged island sources), as discussed in the subsection on manganese.
The advantage of this alternative is that if the research achieves a breakthrough, some of our dependence will be reduced. The disadvantage is that there are no guarantees that a breakthrough will occur.

Recycling efforts also provide an alternative source of some strategic materials. Although recycling is not feasible for all strategic materials, or for all applications of each, recycling can provide an alternative source for some types and applications. Since this feature is application specific, it will be discussed in the last subsection.

FUNDING RESEARCH ON ALTERNATIVE MATERIALS

The fourth alternative is to fund research into alternative materials to replace strategic materials. An example of alternative-material research is the attempt to find a suitable replacement for platinum. Several research efforts are underway in different parts of the country for alternative materials, as discussed in the previous section.

Overall, there appears to be a trend in the industrialized world toward manufacturing advanced materials out of common substances. For example, carbon is a common material, but becomes an advanced material when spun into carbon fibers. This option tends to shift our dependence away from strategic materials but toward more complex and difficult domestic production methods that are often more expensive and more energy-intensive and require a high degree of technical sophistication and expertise.\(^1\)

The advantages and disadvantages of funding alternative-material research are the same as funding alternative-source research and possibly even more risky. However, there may be ways to reduce some of the cost. For example, the national stockpile has recently undertaken projects using stockpile resources to support research, since the strategic materials can be returned to the stockpile once the research has been completed.\(^2\) Stockpile materials could similarly be loaned to research facilities seeking comparison data for alternative materials, but this option has not been applied. Recently, legislation was proposed in Congress that would allow stockpile funds to be allocated for research into specific alternative materials. In either case,

\(^1\)Japan appears to be leading in the development of new processes for making advanced materials. If U.S. research is successful, any proprietary technology could help the U.S. economy and the balance of trade.

\(^2\)For example, approximately 1,500,000 troy ounces of silver were on loan to a government agency as of September 30, 1990.
these seem to be reasonable tasks to be undertaken by the national stockpile authority, since the objective is to reduce our dependence on strategic materials, rather than simply maintain a full stockpile.

Increased conservation of strategic materials is also a viable component of this option. Since conservation usually entails the replacement or substitution of a strategic material by another material, conservation is included under the alternative-materials option. For example, the domestic consumption of chromium could be reduced by replacing chrome surfaces with brushed nickel surfaces. Since the replacement of one strategic material by another material is application and material specific, that information is presented in the next subsection.

HEDGING OPTIONS APPLIED TO THE FIVE SELECTED STRATEGIC MATERIALS

This last subsection discusses the four preceding hedging strategies as applied to the five strategic materials from southern African nations upon which the United States is currently dependent. In Table 4.1, the contribution of recycling efforts is included under alternative sources, while the contribution of consumption reduction efforts is included under alternative materials. Each hedging option will be examined below for its current application to the five selected strategic materials.

Stockpile Purchases

The stocks of ferrochromium and ferromanganese exceed the current goals, while the cobalt stockpile is continuing to increase over 60 percent. Although the stock of chromite is only half of the goal, the chromite goal is likely to be reduced in the near future. DoD has recommended significant reductions in the goals for cobalt, chromium, and manganese. Over two-thirds of the current manganese metal goal has been achieved.

However, the stocks of PGMs and vanadium are well below the specified goals. Part of the problem is that the PGMs are expensive. In addition, there is no stockpiling of rhodium or ruthenium, even though stockage goals have been set. Unless DoD's recommended changes in the goals for PGMs and vanadium are enacted or the stocks increased, there will continue to be a large shortfall in these two strategic materials.
### Table 4.1

The Hedging Options Applied to the Five Materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Stockpile Status</th>
<th>Industry Incentives</th>
<th>Alternative Sources</th>
<th>Alternative Materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chromium</td>
<td>Ferrochromium exceeds goal&lt;sup&gt;a&lt;/sup&gt;</td>
<td>No domestic production&lt;sup&gt;c&lt;/sup&gt;</td>
<td>Recycle: 21% dom. consum.&lt;sup&gt;a&lt;/sup&gt;</td>
<td>FeCr: none&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Chromite: 50%&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Alt. sources: limited qty.&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Refract: good&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Chem: good&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Alloys: moderate&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Reduce dom. consum.: good&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Cobalt</td>
<td>Cobalt: 62% and rising&lt;sup&gt;a&lt;/sup&gt;</td>
<td>No domestic production&lt;sup&gt;c&lt;/sup&gt;</td>
<td>Recycle: 16% dom. consum.&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Alloys: moderate&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Alt. sources: limited qty.&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Magnets: good&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Machinery: moderate&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Manganese</td>
<td>Ferromanganese exceeds goal&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Only low grade (&lt;35%) Mn good for only 1% of consumption&lt;sup&gt;c&lt;/sup&gt;</td>
<td>Recycle: high in steel scrap&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Catalysts: moderate&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Metal ore: 67%&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Alt sources: undersea&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Paints: good&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Low sulfur Fe: moderate&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>PGMs</td>
<td>Rhodium: 0%&lt;sup&gt;c&lt;/sup&gt;</td>
<td>Small number of domestic mines&lt;sup&gt;c&lt;/sup&gt;</td>
<td>Recycle: high&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Electronics: moderate&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Ruthenium: 0%&lt;sup&gt;c&lt;/sup&gt;</td>
<td>Large domestic recycling industry&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Ltd. U.S. prod.&lt;sup&gt;c&lt;/sup&gt;</td>
<td>Catalysts: none&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Others: low %&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Alt. sources: limited qty.&lt;sup&gt;c&lt;/sup&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vanadium</td>
<td>Vanadium: low%&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2/3 U.S. V prod. for domestic use processing fly-ash, etc.&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Recycle: high for dom. consum.&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Steel: limited&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Alt. sources: moderate&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Ti alloy: none&lt;sup&gt;c&lt;/sup&gt;</td>
<td>Sulfuric acid: limited&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Chem: moderate&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
</tbody>
</table>

**NOTE:** Stockpile status is based on statutory goals as of June 1, 1992.

<sup>a</sup> Good or high.  <sup>b</sup> Moderate.  <sup>c</sup> Poor or low.
Industry Incentives

The option to offer incentives to selected industries to maintain production of strategic materials is only applicable to those materials that are produced in the United States. Since there is no domestic production of chromium or cobalt, this option does not apply to these cases. In addition, the only domestic production capability for manganese is low grade (less than 35 percent) and therefore is applicable to only 1 percent of domestic consumption. Note that the strategic materials with the best stockpile fill are those for which the United States does not have a domestic production capability.

There are, however, a number of small domestic PGM mines in the United States, as well as substantial facilities for producing vanadium from fly-ash and other residues imported from other nations. A number of recycling facilities for PGMs exist in the United States, especially those based on automobile catalytic converters. In addition, 50 percent of the U.S. exports of PGMs are in the form of materials to be recycled.

Therefore, the United States could undertake incentives to increase the domestic recycling of PGMs, rather than exporting so much for overseas recycling. Another option might be to increase the benefit for domestically recycling automobile catalytic converters. A more detailed examination of these options would have to be undertaken to determine their feasibility and side effects. For example, a large incentive for recycling catalytic converters could lead to increased theft of catalytic converters from functioning automobiles.

Alternative Sources

Domestic recycling efforts produce 21 percent of the chromium and 16 percent of the cobalt used in our annual domestic consumption. In addition, a large amount of manganese is recycled in steel scrap, although little manganese metal is recycled. As mentioned above, the domestic recycling industry for PGMs is large but could be expanded. The U.S. production of vanadium from imported waste materials is also significant, providing two-thirds of our domestic consumption. For each of the five strategic materials, the United States has a significant recycling effort under way. Incentives for improving the domestic recycling effort were discussed above.

The number of options available as alternative sources of the same materials is somewhat limited. There are few locations outside of southern African nations where both the quantity and quality of chromium and cobalt are available. The case for PGMs is similar,
with 95 percent of the PGMs produced by either the former USSR or the Republic of South Africa.

The domestic production of vanadium relies heavily on imported residues that contain vanadium. The United States could investigate ways to better ensure the flow of these residues in a time of emergency.

The only other area where the United States government could provide alternative sources for these materials is in exploring the use of undersea sources of manganese. Research is already under way on methods to exploit manganese nodules from the ocean floor and manganese from crusts (submerged islands).

**Alternative Materials**

The options for alternative materials vary widely as a function of the strategic material and the specific application. Each will be addressed below.

Chromium is used in stainless steel production (as ferrochromium), as a refractory, in chemical processing, and in superalloys. There are no viable substitutes for ferrochromium in the steel industry. There are good alternatives for chromium used as a refractory, possibly providing up to a 90 percent reduction in chromium consumption in this area over the next ten years. Chromium use in superalloys could also be reduced by 60 percent of current consumption in this area, but many of the candidate substitutes are also on the strategic materials list. Some chromium used in the chemical industry could be replaced, thereby saving 15 percent of the consumption in this area. However, all of these substitutions will decrease performance and increase cost.

Cobalt has few substitutes in its many applications. Nickel can be used as a substitute in superalloys and other applications, but at increased cost and decreased performance. If they are found to be reliable, advanced ceramics may be able to substitute for cobalt in these applications. In magnets, nickel, platinum, barium, strontium ferrite, and iron may be used as substitutes. In machinery, nickel, tungsten, molybdenum carbide, and ceramics could be used. Nickel could also be used as a substitute for cobalt in catalysts. In paints, copper, chromium, and manganese could substitute for cobalt. Once again, many of the substitutes are themselves strategic materials, and some are obtained from southern African nations.

Manganese does not have any feasible substitutes in the steel industry, although a few substitutes exist in the superalloy industry. In
the steel industry, aluminum and zirconium could be substituted for manganese as a deoxidizer, and using low-sulfur iron ore would reduce the demand for manganese. However, each of these options increases cost.

PGMs also have few substitutes. Gold could be substituted for palladium-and-silver contacts in electronics, but also at increased cost. There are no good substitutes for the PGMs used in catalytic converters, except for other PGMs.

Vanadium has no substitute as an alloy of titanium in aerospace applications. Vanadium pentoxide could be replaced by the old “lead box” technique for producing sulfuric acid, but at a significantly higher cost. Platinum and nickel can replace vanadium compounds in other chemical applications, but at much higher cost. Such materials as columbium, manganese, molybdenum, titanium, and tungsten may be substituted for vanadium in steel alloys, but at a loss of performance. Once again, the candidate substitutes for vanadium tend also to be strategic materials.

Overall, it appears that opportunities for government to support research on alternative materials for these five strategic materials are somewhat limited. The areas worth investigating include

- Replacing chromium in refractories, superalloys, and chemical processes;
- Replacing cobalt in superalloys, magnets, machinery, catalysts, and paint;
- Substituting for manganese in superalloys and deoxidizers; and
- Substituting for vanadium in chemical processes.

This does not imply that hedging by finding alternative materials is not a viable option, but simply that the feasibility of using this option with three of the five selected strategic materials (manganese, PGMs, and vanadium) is rather limited. In most of the cases listed above, the substitute materials tended also to be strategic materials, some of which are also obtained from southern African nations.
5. CONCLUSIONS

CURRENT U.S. DEPENDENCE ON MATERIALS FROM SOUTHERN AFRICAN NATIONS

Southern African nations account for 10 percent or more of the world’s production of antimony, chromium, cobalt, industrial diamond, manganese, PGMs, titanium, and vanadium. Three of these materials (antimony, industrial diamond, and titanium) can easily be obtained from a variety of other sources. The lowest-cost significant deposits of the remaining five are located in southern African nations.

The United States is very dependent on southern African nations to supply two of these strategic materials (chromium and cobalt) and somewhat dependent on southern African nations for three other strategic materials (manganese, PGMs, and vanadium).

The primary reason for the U.S. dependence on chromium and manganese is the U.S. steel industry. The United States produces an average of between 75 and 100 million tons of steel each year, all of which requires manganese of consistent grade and with few impurities. Inconsistencies or unknown impurities in the ore can make a batch of steel useless. The most consistent grades of manganese ore are produced by the Republic of South Africa.

One million tons of stainless steel are produced in the United States each year, all of which requires a minimum of about 11 percent and an average of 17 percent chromium. Grade consistency and known impurities are the key to the automated production of good quality stainless steel. The very magnitude of use of both manganese and chromium makes it very unlikely that there will be a significant shift in the use of these materials by the end of the decade. Steel, stainless and otherwise, is important to the defense industry.

The United States is dependent on cobalt and somewhat dependent on PGMs and vanadium. Cobalt has many unique properties and is used as a component in superalloys, cemented carbides, and magnets; as a bonding material for enamels and organics, such as rubber; as a catalyst in the oil and chemical industries; as a paint dryer; and in camouflage paints for reducing detectability by infrared sensors. PGMs are used extensively in electronics and in the production of advanced carbon-fiber materials. Vanadium is an essential element in high-strength steels and in the production of sulfuric acid, a key in-
redient in the chemical industry, which in turn is essential to the munitions industry.

The lowest-cost significant deposits for the production of cobalt, PGMs, and vanadium are in southern African nations. Since these three materials are produced as byproducts or coproducts, their production is more economical than if they were mined alone. Nations with smaller economical deposits cannot compete as well in the open market. The United States would not be able to quickly compensate for a sudden shortage in these three materials, because of the long lead times involved in mine development. In the event of a shutdown in the supply of these materials from southern African nations, the United States could expect significant increases in the price of cobalt, and possibly PGMs and vanadium, while the rest of world production expanded to meet the demand. The cobalt crisis of 1979 was a good example of the effects of this dependency.

HEDGING AGAINST DEPENDENCE

Four options are available for hedging against these dependencies: purchasing and stockpiling strategic materials, providing incentives for domestic production of strategic materials, funding research into alternative sources of the same materials, or funding research into alternative materials. Described below are the advantages and disadvantages to each option, as well as the status of each hedging option as applied to the five selected strategic materials.

Purchase Stockpile

The primary advantage of stockpiling is that the stockpile could be used to protect us from the worst-case scenario of a protracted conventional war. Stockpiles can carry the nation's demand through a period of supply disruption while alternative sources of the same or alternative materials are expanded to fill the related demand. Stockpiles could also protect the nation from economic shocks unrelated to military action against the United States. However, there is no legal basis for the use of the stockpile in peacetime. The disadvantages are that stockpiles are expensive and not necessarily responsive to rapid changes in specific production requirements (such as level of purity). In addition, when stockpiled materials are sold or simply announced to be for sale, such actions immediately create their own shocks to the material industry.

Given the current legislated goal levels, the current stockpile levels of chromium, cobalt, and manganese are good, but the levels for PGMs
and vanadium are poor. Unless the new DoD-recommended stockpile goals for these materials are enacted or the stocks increased, there will continue to be a significant shortfall in PGMs and vanadium.

Provide Industrial Incentives
The advantage of providing incentives to existing domestic producers is that it helps fund an existing operation. The two disadvantages are that this option expends funds on an operation that is already not economically competitive and that is only applicable to cases in which an operation already exists. Since most of our domestic production capabilities for strategic materials no longer exist, this option is not applicable to most strategic materials. However, there are significant domestic recycling industries for chromium, cobalt, manganese, and PGMs, and there is a domestic vanadium production industry based on processing imported residues containing vanadium. Industrial incentives would be best applied to securing vanadium residues for domestic processing and to encouraging the domestic recycling industries for chromium, cobalt, manganese, and PGMs.

Research Alternative Sources
The advantage of funding research into alternative sources is that, if it is successful, we will be less dependent on existing sources of these materials. The disadvantage is that, like all research, there is no guarantee that the research will succeed. In terms of natural resources, the only area of likely success is in the exploitation of manganese from undersea nodules and crusts.

Recycling, however, presents several possible areas of effort. For example, recycling provides 21 percent of the domestic consumption of chromium and 16 percent of the domestic consumption of cobalt. About half of the U.S. exports of PGMs is to foreign recycling centers. Manganese is recycled as a component of scrap steel. Therefore, the most promising areas for funding alternative-source research are in exploiting undersea sources of manganese and improving the domestic recycling industries for chromium, cobalt, and PGMs.

Research Alternative Materials
The advantage of funding research into alternative materials is that, if it is successful, we will be less dependent on strategic materials. The disadvantages are that searching for alternative materials is even more risky than searching for alternative sources of the same material and that there is no guarantee the research will succeed.
Research into the substitution or replacement of strategic materials appears feasible in the following areas: replacing chromium in refractories, superalloys, and chemical processes; replacing cobalt in superalloys, magnets, machinery, catalysts, and paint; substituting for manganese in superalloys and deoxidizers; and substituting for vanadium in chemical processes.

One area of concern is that many of the alternative materials are also strategic materials, and some also originate in southern African nations. For example, possible substitutes for vanadium include manganese and titanium. Even technologies that use “common materials” (e.g., carbon fibers and ceramics) sometimes rely on strategic materials, such as PGMs for the spinnerets used to produce carbon fiber thread.

PREDICTING FUTURE DEMAND FOR STRATEGIC MATERIALS

We believe there will not be a significant change in the composition of strategic materials by the end of the decade for three reasons: the magnitude of current use, inertia in the major industries, and a reduced military budget. First, the magnitude of the use of strategic materials in military, industrial, and civilian sectors is very large and would require significant changes to shift from current levels to new levels. For example, the U.S. steel industry produces between 75 and 100 million tons of steel annually, which would be difficult to replace with alternative materials. The United States consumes very large quantities of many of these strategic materials, especially cobalt, chromium, and manganese. As a result, it is unlikely that there will be a rapid shift to alternative materials for most applications.

Second, some industries, such as the steel, superalloys, and electronics, have invested a great deal in automation to meet the very strict and precise requirements of modern production techniques. This automation would be expensive to change, and there is currently insufficient economic incentive to make such drastic changes.

Third, the military budget is decreasing. As a result, any investment in new types of military assets will be more limited than in the recent past. Any change in the composition of the strategic materials will take some time to filter through the system, given the projected low production rates.

As a result of these three factors, we do not anticipate a major shift in the demand for the eight strategic materials examined in this study by the end of the decade.
Appendix A

SELECTED BACKGROUND INFORMATION ON
THE U.S. STEEL INDUSTRY

This information is presented in a question and answer format. Except for the first question, the following information was gathered from a telephone interview with Anthony Peters, Physical Scientist at the U.S. Bureau of Mines, on September 30, 1991. The answer to the first question was provided by Gerald Houch after Mr. Peters retired.

IS THE U.S. STEEL INDUSTRY DECLINING IN PRODUCTION CAPACITY?

The apparent U.S. steel supply includes U.S. production and foreign inputs minus exports and has been stable at between 95 and 100 million tons annually for quite some time. In 1990, U.S. steel production exceeded 89 million tons. U.S. steel production is not influenced primarily by demand but by international monetary exchange rates. For example, the strong U.S. dollar of the 1980s caused U.S. production to fall off and imports of steel to increase. The current weaker U.S. dollar encourages domestic production.

HOW IS STEEL PRODUCED?

Modern steel-manufacturing is a two-stage process. The first stage uses electric-arc furnaces, in which the constituent elements (iron ore, ferroalloys, scrap metal) are melted. The second stage uses argon-oxygen furnaces, in which the product is further refined and impurities are removed. The vast majority of U.S. steel producers use the electric-arc and argon-oxygen process, although a few producers still use blast furnaces to produce steel. This two-stage process is expensive, but it is the most reliable and produces the highest quality steel. The U.S. steel industry uses a wide variety of additives that give different types of steels unique properties for particular applications (such as vanadium in high-strength steels).

In contrast, the Soviets refine steel primarily by electric-arc furnace only, which yields low-quality steel—steel that the U.S. industry would consider “junk.” The Soviets have produced high-quality steel in only a few select defense applications in which cost does not matter.
IS THERE INERTIA IN THE STEEL INDUSTRY THAT REDUCES FLEXIBILITY?

Steel manufacturing can be a flexible system, but there are economic constraints on production. Steel production in the United States is controlled electronically, and this promotes uniformity of production. The industry has determined the economically optimal methods for producing a particular grade of steel with specific properties, and in turn, this requires raw materials of high consistency. There is a large amount of inertia in the industry, because the producers have made a huge investment in the facilities. If there is a miscalculation during production, the producers risk producing scrap metal or damaging their equipment.

Modern steel production works within extremely narrow specifications, and the steel-making process has been geared toward raw materials with specific attributes and impurities, which is why producers are very reluctant to take in ore from unfamiliar sources. This is a major reason for our continued dependence on southern African nations for chromium. Producers are adverse to experimenting with “unknown” ores, as they face the risk of potentially huge losses.

The steel industry has traditionally been very conservative, with only incremental changes occurring at a slow pace. This is due in part to the fact that, up until about ten years ago, the boards of directors of steel corporations had been composed almost exclusively of financiers, lawyers, or bankers. About ten years ago, the steel industry entered a major slump, whereupon more “steel industry people” were brought on board, and the industry has become more responsive.

WHY DO MINIMILLS REQUIRE SILICOMANGANESE?

The U.S. steel industry has two parts: “integrated,” which mines the ore and produces iron using blast furnaces, then refines the crude iron into steel, and “minimills,” which process steel scrap to produce steel. Minimills rely on scrap to produce steel and have grown at the expense of integrated producers.

For economic and technical reasons, minimills have a preference for using silicomanganese to add silicon and manganese. Minimills use electric-arc furnaces and “cut corners” by using metal scrap for raw material, which they then refine and roll into steel. The minimills rely on silicomanganese slag, which is virtually a byproduct of ferromanganese production. You cannot produce steel without producing scrap. Integrated producers add silicon to their ferromanganese
scrap, producing silicomanganese scrap, which the integrated producers in turn sell to the minimills.

ARE THERE ALTERNATIVES TO THE METALS CURRENTLY USED TO ALLOY STEEL?

Most alloying substances have substitutes. For example, vanadium can be replaced by columbium (also called niobium), but there are no substitutes for chromium or manganese. Stainless steel usually contains 17 percent chromium; steel with a minimum of 11 percent chromium possesses a continuous covering layer of transparent oxide, which is very tenacious and impervious to water, oxygen, etc. These properties produce a steel surface that is highly corrosion-resistant, which is due exclusively to the chromium in the stainless steel.

Attempts have been made to find alloys other than chromium that have similar properties and corrosion resistance, but without success. For example, titanium has been alloyed with steel, but the resulting oxide covering appears as an opaque white sheen that is brittle.

Manganese is irreplaceable in steel production as a desulfurizer and deoxidizer, and for which there are no reasonable substitutes.

ARE THERE VIALBLE SUBSTITUTES FOR HIGH-STRENGTH ALLOYED STEEL?

So much steel is used in so many applications that it is hard to conceive of anything substantially replacing it.

COULD TITANIUM BE USED AS A SUBSTITUTE?

The United States produces over 75 million tons of steel annually. It is unlikely that titanium production for civilian uses could begin to approach this amount.

IS THE HISTORY OF ALUMINUM ANY GUIDE TO THE INCREASED UTILIZATION OF TITANIUM?

Both high-grade aluminum and titanium production are energy-intensive, requiring special techniques. For example, both aluminum and titanium require oxygen-free (submerged) environments for welding. The development of aluminum production was motivated by the need for a lightweight, fairly strong metal. However, the existence of aluminum now works against the use of titanium as a substitute.
COULD CARBON FIBER BE USED AS A SUBSTITUTE?

The techniques involved in producing carbon fiber are highly complex and may not lend themselves to mass production, although composite materials are gaining wider use.
Appendix B

DISCUSSION OF ANTIMONY, INDUSTRIAL DIAMOND, AND TITANIUM

Although southern African nations produce over 10 percent of the world’s production of antimony, industrial diamond, and titanium, the United States is not dependent on the supply of these materials from southern African nations. These materials were selected as candidates for study by the screening process described in Section 2. However, upon detailed examination, we found that alternative sources of the same or substitute materials were available.

ANTIMONY

Demand or Use of Antimony by Type and Quantity

Seventy percent of antimony (Sb) is used as a fire retardant in textiles and plastics, in which Sb$_2$O$_3$ is used to bind organic compounds. Ten percent of antimony is used in the chemical industry as a catalyst. Another 10 percent is used in the transportation industry, because antimony is commonly used to harden alloys, such as lead, which is commonly used in automobile batteries. The final 10 percent is used in ceramics, glass, and other products (see Figure B.1).

The primary defense applications of antimony are to make fire-retardant tents and various batteries and in hardening lead bullets.

The overall consumption of antimony appears stable.\(^2\)


\(^2\)The national defense stockpile nearly tripled the goal for antimony in June 1991. However, a more recent update of July 1991 cites a drastically lower goal of only 15,645 metric tons. This rapid fluctuation may have been a reporting error in the June 1991 goal. There is no known reason why any significant change should have occurred. Because of recent world events, the February 1992 update recommends a zero stockpile goal for antimony.
Production Location and Methods for Antimony

Antimony is recovered as a byproduct from the smelting of domestic lead and silver-copper ores. Domestic production of antimony was about $53 million in 1990. There are no quality or grade restrictions on antimony.

Total antimony imports are from the following nations: China, 49 percent; Republic of South Africa, 14 percent; Mexico, 11 percent; Hong Kong, 7 percent; and other nations, 19 percent.³

Possible Substitute Sources for Antimony

Antimony is widely distributed worldwide, with 21 percent of reserves held by the United States, Bolivia, Mexico, Republic of South Africa, and Yugoslavia. The remaining 79 percent of the reserves is held by other nations around the world.

³Of the other nations, the U.S. imports from Belgium, France, and Hong Kong, but these nations first import the raw antimony ore from China, South Africa, and Bolivia.
The United States commonly produces Sb₂O₃ from antimony metal imported from China. The metal is preferred over raw ore because of domestic pollution control regulations regarding antimony production. The United States had previously preferred to buy Sb₂O₃ from South Africa, but switched to buying from China when it decided to sell Sb₂O₃ along with antimony metal. No other producers have been able to compete with China's relentless cost-cutting.⁴

Approximately 15,000 tons of antimony were recycled from old scrap, 97 percent of which was recovered as antimonial lead and subsequently consumed by the battery industry.

Options for Alternative Materials for Antimony

There are many acceptable substitutes for most antimony applications, but with the price of antimony so depressed by China, it is clearly the most economical choice at this time.

It is possible that tin may replace antimony as a fire retardant. Lead batteries may be replaced by nickel-cadmium batteries.

Overall Degree of U.S. Dependence on Antimony from These Nations

The United States is not dependent on antimony from southern African nations. If the United States were cut off from its sources in China and South Africa, the rest of the world would be able to provide an adequate supply.

The national stockpile status of antimony showed a significant shortfall in reaching the statutory goal, but the goal is under revision for reasons mentioned above.

⁴However, according to the second quarter U.S. Bureau of Mines Mineral Industry Survey, "On April 25, 1991, a coalition of five U.S. antimony trioxide producers and/or manufacturers of antimony trioxide-based products filed an antidumping petition with the International Trade Commission (ITC) and the Department of Commerce, charging China with unfair trade practices."
INDUSTRIAL DIAMOND

Demand or Use of Industrial Diamond by Type and Quantity

Industrial grade diamond (both stone and dust) is used in a variety of industrial applications. For example, the mining industry uses industrial grade diamond imbedded in drilling bits, because of its hardness and durability. Approximately 59 percent of the diamond stones were consumed in drilling operations. Diamond dust is often used in cutting hard materials, such as gemstones.

Industrial grade natural diamond was consumed by the following domestic industries last year: machinery, 27 percent; mineral services (primarily drilling), 18 percent; stone and ceramic products, 17 percent; abrasives, 16 percent; contract construction, 13 percent; transportation equipment, 6 percent; and other, 3 percent (see Figure B.2).

Specific defense applications include the need for small Type II-B gem-quality diamonds for use in special electronic devices. Since it takes time to produce these diamonds, the U.S. military reportedly has a four- or five-year supply of Type II-B gem-quality diamonds. However, this supply is not part of the National Defense Stockpile. Overall, our need for gem-quality diamonds in such specific applications would be easily met by the domestic jewelry market.

Production Locations and Methods for Industrial Diamond

Total worldwide natural diamond production is around 95 million carats. Of this, Australia produces 35 percent, or approximately 34 million carats. Southern and central African nations provided 49 percent of the world production of natural industrial grade diamond. Zaire led with 30 percent, followed by Botswana with 10 percent, and South Africa with 9 percent.

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6Contract construction refers to building construction primarily in retrofitting old buildings to meet new standards. Industrial diamond is used extensively in drilling and sawing walls that will remain while the retrofit is performed.
Natural stone diamonds of industrial grade were imported to the United States from Ireland, 22 percent (a transshipper); Republic of South Africa, 18 percent; Zaire, 18 percent; United Kingdom, 17 percent (a transshipper); and other nations, 25 percent. In addition, the United States imported natural and synthetic grit, bort, powder and dust from Ireland, 66 percent; Japan, 10 percent; United Kingdom, 4 percent; Belgium, 3 percent; and from other nations, 17 percent. However, the diamonds imported from most of the nations listed above originate in southern African nations or Australia.

World production of industrial grade natural diamonds comes from Australia, 33 percent; Zaire, 30 percent; China, 14 percent; Botswana, 10 percent; South Africa, 9 percent; and from other nations, 4 percent.

The United States does not produce natural diamond, but does produce synthetic diamond from synthetic grit and powder. Two companies, General Electric (U.S.) and DeBeers (South Africa), produce 85 percent of the world's synthetic diamonds.

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7Bort is a low-quality diamond, in granular aggregate or small fragments, especially for use as an abrasive.
Possible Substitute Sources for Industrial Diamond

In the United States, 6.3 million carats of industrial grade diamond were recovered as a secondary operation (from salvage stone, sludge, and swarf).\(^8\) This is in addition to the synthetic diamond produced domestically.

As mentioned above, Australia and China are the two alternative locations for producing natural industrial grade diamonds outside of southern African nations.

Options for Alternative Materials for Industrial Diamond

Synthetic industrial diamond production maintained its record-high level in 1990. All domestic industrial diamonds were synthetic. Substitute materials include manufactured abrasives (cubic boron nitride, fused aluminum oxide, and silicon carbide) and natural abrasives (garnet, emery, and corundum). Synthesized polycrystalline diamond competes well with natural diamond in many applications. Other substitute forms include specialized shapes for synthetic diamond, including films and carbon coatings of extreme hardness.

Overall Degree of U.S. Dependence on Diamond from These Nations

The United States is not dependent on natural industrial grade diamonds from southern African nations. Much of the domestic consumption of industrial diamond could be satisfied by synthetic diamonds produced domestically. Recycling provides an additional source of industrial grade diamond. In wartime, the United States could reduce the demand for industrial grade diamond by eliminating nonessential drilling and by reducing the export of drill bits.

Furthermore, the total U.S. annual requirement for industrial diamonds could conceivably be transported in one aircraft or one submarine retrieving diamonds from where they are already stockpiled in the diamond industry (e.g., the United Kingdom, Belgium, or Australia). The U.S. national stockpile (which is on U.S. soil) is currently at a satisfactory level for industrial grade diamond.

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\(^8\)Swarf is an accumulation of fine particles of metal or abrasive cut or ground from work by a machine tool or grinder.
TITANIUM

Demand or Use of Titanium by Type and Quantity

Titanium is used in two forms: titanium metal and titanium oxide pigment. Overall, only 5 percent of the imported titanium is used as metal, while 95 percent is used as pigment.

In 1990, about 80 percent of the titanium metal imported was used in jet engines, airframes, and space and missile applications. Another 20 percent was used in chemical processing, power generation, marine and ordnance, medical, and other nonaerospace applications. The total value of titanium metal consumed in the United States was $275 million in 1990 (see Figure B.3).

Titanium oxide pigment was consumed in the following ways: paints, varnishes, and lacquers, 50 percent; paper, 26 percent; plastics, 16 percent; rubber, 1 percent; and other uses, 7 percent. The total cost of titanium pigment was $2.2 billion in 1990. The main advantage of titanium oxide pigment is its ability to provide the "one-coat" paint. No other material provides as much coverage or is as reflective as titanium oxide paints.

Two common forms of titanium ore are ilmenite and rutile. Ilmenite and 80 percent titanium dioxide (TiO₂) slag are used only for TiO₂ pigment production. Rutile, synthetic rutile, and 85 percent TiO₂ slag can be used either for pigment or titanium metal production.

The flow of titanium into the United States tends to fluctuate widely over time, depending on the demand for high-performance aircraft production. Since the demand for new high-performance aircraft will probably be down over the next few years, the U.S. demand for titanium metal will also probably decrease as well.

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Production Locations and Methods for Titanium

The only titanium item that the United States imports from southern African countries is titanium slag from the Republic of South Africa. The slag is produced by Richards Bay Minerals, Richards Bay, South Africa, and it contains 85 percent titanium dioxide (TiO₂). This slag is used as feed for producing titanium tetrachloride (TiCl₄), which is the precursor for titanium sponge used to produce titanium metal, and it is used as feed for the sulfate process for producing TiO₂ pigment. Titanium slag from South Africa competes with rutile and synthetic rutile for TiCl₄ production, and it competes with ilmenite in sulfate-process TiO₂ pigment production.

There are no titanium metal production or fabrication facilities in southern Africa, and the United States receives virtually no metal imports from this area.

The determination of trade patterns in both titanium concentrates and titanium metal is relatively straightforward. Few, if any, transshipments or intermediaries are involved in titanium trade.
Possible Substitute Sources for Titanium

The United States imports titanium metal from the following countries: Japan, 85 percent; China, 14 percent; and other, 1 percent. Japan is focusing on being the processor of high-grade refined metals, such as titanium, rather than as a source of raw materials.

Titanium dioxide pigment comes from the following countries: Germany, 20 percent; Canada, 16 percent; France, 14 percent; United Kingdom, 13 percent; Spain, 10 percent; and other, 27 percent. Only a small amount of titanium dioxide comes from southern African nations.

In 1989, 77 percent of ilmenite ore, 57 percent of the natural rutile ore, and 84 percent of the synthetic rutile that the United States imported came from Australia. The United States also imported 30 percent of its titanium slag and all of its titaniferous iron ore from Canada. Less than 25 percent of the U.S. imports of natural rutile come from South Africa. However, 70 percent of the titanium slag with 85 percent TiO₂ which is used to make both the metal and the pigment, comes from the Republic of South Africa.

An 80 percent TiO₂ titanium slag is produced in Canada, but this can only be used for sulfate-process TiO₂ pigment production. Because of calcium and magnesium impurities, which cause operating problems in the chlorinators, it is not suitable for TiCl₄ production.

In case of an emergency, synthetic rutile could be produced from domestic ilmenite currently being mined in Florida or from ilmenite sand deposits in Tennessee. In addition, TiCl₄ could be used for metal production directly from ilmenite using domestic production facilities.

Titanium scrap metal can be recycled, and 16,000 tons were recycled in 1990. Another 4,000 tons of ferrotitanium alloy were recycled, along with 500 tons in the aluminum industry and 50 tons from other alloys. Between 200 and 400 tons of old titanium metal scrap were recycled.

Titanium oxide is not recyclable.

Options for Alternative Materials for Titanium

There are no substitutes for TiO₂, especially in paints. There is no substitute for titanium in aircraft and space applications without a sacrifice in performance. Some aerospace applications could use advanced graphite composites, but whether these applications are successful is currently unclear. For less demanding industrial uses,
high-nickel steel, zirconium, and some superalloy metals may be substituted for titanium.

**Overall Degree of U.S. Dependence on Titanium from These Nations**

The United States is not dependent on southern African nations for titanium. It is unlikely that there would be a shortage of titanium metal for defense purposes in the foreseeable future, especially since the demand for end products, such as a large number of high-performance aircraft, is likely to decrease. The demand for titanium oxide is likely to remain fairly constant.

The stockpile of rutile contains 37 percent of the current goal, while the stockpile of titanium sponge (for producing titanium metal) contains only 19 percent of the current stockpile goal. Since the demand for titanium will probably decrease along with the defense budget, the stockpile may be sufficient for projected needs. Ilmenite is not included on the list of strategic materials primarily because domestic production capabilities are sufficient.

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10Based on historical data, the demand for titanium metal is closely tied to the number of high-performance aircraft under construction. When the number of high-performance aircraft orders has been low, the U.S. demand for titanium metal has been low. Even though the quantity and percentage of titanium metal used in high-performance aircraft and space vehicles have increased, this has not yet been offset by the decrease in the quantity of orders.
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