Does the US Military Have Enough Minerals for a Possible Conflict with China?: Estimating Shortfalls for Military Materials

By Gregory Wischer and Morgan Bazilian

Abstract: The National Defense Stockpile is a tool to both reduce America's reliance on foreign materials, especially materials from China, and to prepare for a possible conflict. However, the Department of Defense does not publicly release its biennial stockpile assessment, which analyzes what materials may be in shortfall during a conflict. And even if publicly released, the biennial stockpile assessment—if the publicly available 2015 assessment is indicative—does not specifically delineate the military's projected shortfall quantities for individual materials. This paper provides a simple methodology to estimate the US military's shortfall risks for twenty-three materials in three different conflict scenarios with China. It finds that the following nine materials have the highest shortfall risk: antimony, bismuth, cobalt, niobium (columbium), metallurgical-grade fluorspar, acid-grade fluorspar, iridium, nickel, and titanium sponge.

1. Introduction

The US National Defense Stockpile is used both to reduce America's reliance on foreign materials, especially materials from China, and to prepare for a conflict.[1] The stockpile is managed by the Department of Defense, specifically the Defense Logistics Agency's Strategic Materials office, and it contains materials that support vital domestic industries during national emergencies like war.[2] However, the Department of Defense does not publicly release its biennial stockpile assessment,[3] which analyzes what materials may be in shortfall during a conflict.[4] And even if publicly released, the biennial stockpile assessment—if the publicly available 2015 assessment is

[1] White House, "Building Resilient Supply Chains, Revitalizing American Manufacturing, and Fostering Broad-Based Growth: 100-Day Reviews under Executive Order 14017," June 2021, 16, 130–131, 152–153, 175–179, 184–189, 200–201, https://www.whitehouse.gov/wp-content/uploads/2021/06/100-day-supply-chain-review-report.pdf; and US Department of Defense, "Securing Defense-Critical Supply Chains: An Action Plan Developed in Response to President Biden's Executive Order 14017," February 2022, 43–45, https://media.defense.gov/2022/Feb/24/2002944158/-1/-1/1/DOD-EO-14017-REPORT-SECURING-DEFENSE-CRITICAL-SUPPLY-CHAINS.PDF.
[2] Cameron Keys, "Emergency Access to Strategic and Critical Materials: The National Defense Stockpile," Congressional Research Service, November 14, 2023, https://crsreports.congress.gov/product/pdf/R/R47833.
[3] Defense Logistics Agency, email message to author, December 1, 2023.
[4] Cameron Keys, "Emergency Access to Strategic and Critical Materials: The National Defense Stockpile," Congressional Research Service, November 14, 2023, 8–9, 20, https://crsreports.congress.gov/product/pdf/R/R47833.

indicative—does not specifically delineate the military's projected shortfall quantities for individual materials.[5] The assessment only lists the names of materials in shortfall for the military,[6] the total value of the military's material shortfall, which combines the shortfalls for all materials,[7] and the total shortfall values and quantities for individual materials, which combines the shortfalls from the military as well as industrial and essential civilian sectors.[8]

Better understanding the military's projected shortfall quantities for individual materials would inform what materials—and corresponding applications—the US military will most likely have shortfalls of during a conflict. Such information could help optimize what materials are stockpiled. This article estimates the US military's shortfall risks for twenty-three materials in three different conflict scenarios. It finds that the following nine materials have the highest shortfall risk: antimony, bismuth, cobalt, niobium (columbium), metallurgical-grade fluorspar, acid-grade fluorspar, iridium, nickel, and titanium sponge.

The remainder of this paper is organized as follows: Section 2 considers the current government assessments, Section 3 describes the methodology, and Section 4 presents the results. Section 5 offers a brief discussion, and Section 6 concludes.

2. Current Government Assessments

Material shortfalls can impact—and have impacted—US warfighting ability. Kenneth Kessel writes in *Strategic Minerals: US Alternatives*, "The record shows that the US capability to wage war in the past has in some cases been impinged on by a lack of adequate supplies of strategic minerals—in large measure because of a national stockpile that was insufficient (a) to offset supply-line interdictions or (b) to bridge the gap between normal industrial output and the time

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[5] Under Secretary of Defense for Acquisition, Technology and Logistics, "Strategic and Critical Materials 2015 Report on Stockpile Requirements," US Department of Defense, January 2015, https://www.hsdl.org/?view&did=764766.
[6] Under Secretary of Defense for Acquisition, Technology and Logistics, "Strategic and Critical Materials 2015 Report on Stockpile Requirements," US Department of Defense, 17–18, https://www.hsdl.org/?view&did=764766.
[7] Under Secretary of Defense for Acquisition, Technology and Logistics, "Strategic and Critical Materials 2015 Report on Stockpile Requirements," US Department of Defense, January 2015, 17, https://www.hsdl.org/?view&did=764766.
[8] Under Secretary of Defense for Acquisition, Technology and Logistics, "Strategic and Critical Materials 2015 Report on Stockpile Requirements," US Department of Defense, January 2015, 16–17, https://www.hsdl.org/?view&did=764766.

necessary to gear up for the sharply higher output needed to support the war effort."[9] In three of its four largest wars—World War I, World War II, and the Korean War—the United States had material shortfalls.[10]

The purpose of the National Defense Stockpile is to help minimize these shortfalls by storing extra materials. Under US law, the stockpile is, "to provide for the acquisition and retention of stocks of certain strategic and critical materials and to encourage the conservation and development of sources of such materials within the United States and thereby to decrease and to preclude, when possible, a dangerous and costly dependence by the United States on foreign sources or a single point of failure for supplies of such materials in times of national emergency."[11]

The Department of Defense's Defense Logistics Agency monitors 283 materials for possible inclusion in the stockpile.[12] It then seeks to stockpile materials expected to be in shortfall for the military, industrial, and essential civilian sectors during a one-year conflict including an attack on the US homeland, followed by a three-year recovery.[13] These shortfalls are calculated with methodologies that integrate demand variables such as weapons platform requirements and supply variables such as foreign mineral imports.[14] As noted by Cameron Keys in a Congressional

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[9] Kenneth A. Kessel, *Strategic Minerals: US Alternatives* (Washington, DC: National Defense University Press, 1990), 52, https://apps.dtic.mil/sti/pdfs/ADA229895.pdf.
[10] John D. Morgan, Jr., "National Stockpile and United States Strategy," Industrial College of the Armed Forces, December 6, 1955, 6, https://www.hsdl.org/?view&did=456593.
[11] 50 U.S.C. § 98a(b), laws in effect as of December 12, 2023, https://uscode.house.gov/view.xhtml?req=granuleid:USC-prelim-title50-section98a&num=0&edition=prelim.
[12] Cameron Keys, "Emergency Access to Strategic and Critical Materials: The National Defense Stockpile," Congressional Research Service, November 14, 2023, 8, https://crsreports.congress.gov/product/pdf/R/R47833.
[13] Cameron Keys, "Emergency Access to Strategic and Critical Materials: The National Defense Stockpile," Congressional Research Service, November 14, 2023, 8–9, 20, https://crsreports.congress.gov/product/pdf/R/R47833.
[14] Under Secretary of Defense for Acquisition, Technology and Logistics, "Strategic and Critical Materials 2015 Report on Stockpile Requirements," US Department of Defense, January 2015, 10–11, Appendix 2-11–2-12, https://www.hsdl.org/?view&did=764766. The Institute for Defense Analyses provides analytic support to the Defense Logistics Agency in estimating material shortfalls. For their methodologies, see Institute for Defense Analyses, "Formal Processes for Mitigating Risks of Strategic Materials Shortfalls," March 2023, https://www.ida.org/-/media/feature/publications/f/fo/formal-processes-for-mitigating-risks-of-strategic-materials-shortfalls/d-33375.ashx; Julie C. Kelly and James S. Thomason, *The Risk Assessment and Mitigation Framework for Strategic Materials (RAMF-SM)* (Alexandria, VA: Institute for Defense Analyses, 2022), https://www.ida.org/-/media/feature/publications/t/th/the-risk-assessment-and-mitigation-framework-for-strategic-materials-ramfsm/d-33112.ashx; Eleanor L. Schwartz and James S. Thomason, *The RAMF-SM Stockpile Sizing Module: Updated Documentation and User's Guide* (Alexandria, VA: Institute for Defense Analyses, 2022), https://apps.dtic.mil/sti/trecms/pdf/AD1199878.pdf; Eleanor L. Schwartz, *The RAMF-SM Material Demand Computation Program: Documentation and User's Guide* (Alexandria, VA: Institute for Defense Analyses, 2022),

Research Service report, the FY2023 stockpile assessment found that the military would have shortfalls in sixty-nine materials totaling $2.41 billion.[15] With current stockpile inventories of $912.3 million, the stockpile would cover about 40 percent of the military's projected material shortfalls.[16]

Various US government-connected entities have emphasized the importance of understanding the US military's material shortfall risks. In a 2008 publication assessing the need for a military stockpile, the National Research Council of the National Academies said that the Department of Defense "would benefit from a serious near-term effort to capture specific defense materials needs," concluding that the "Department of Defense appears not to fully understand its need for specific materials or to have adequate information on their supply."[17] The publication also noted, "The committee is struck by the lack of coordination across the DoD [Department of Defense] and the military services to identify specific individual and shared materials needs."[18] The Institute for Defense Analyses, which provides analytic support to the Defense Logistics Agency in estimating material shortfalls,[19] calculated the military's material usage and shortfall risks in a 2009 Department of Defense report to Congress.[20] The Institute for Defense Analyses stated that "it

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https://www.ida.org/-/media/feature/publications/t/th/the-ramfsm-material-demand-computation-program-documentation-and-users-guide/p-22689.ashx; and Eleanor L. Schwartz and James S. Thomason, *The Material Supply Adjustment Process in RAMF-SM, Step 2* (Alexandria, VA: Institute for Defense Analyses, 2015), https://apps.dtic.mil/sti/tr/pdf/AD1015877.pdf. For a case study by the Institute for Defense Analyses on calculating downstream material shortfall risks, see D. Sean Barnett and Jerome Bracken, *Supply Chain Modeling for Fluorspar and Hydrofluoric Acid and Implications for Further Analyses* (Alexandria, VA: Institute for Defense Analyses, 2015), https://www.ida.org/-/media/feature/publications/s/su/supply-chain-modeling-for-fluorspar-and-hydrofluoric-acid-and-implications-for-further-analyses/d-5379.ashx.

[15] Cameron Keys, "Emergency Access to Strategic and Critical Materials: The National Defense Stockpile," Congressional Research Service, November 14, 2023, 9, https://crsreports.congress.gov/product/pdf/R/R47833.

[16] Cameron Keys, "Emergency Access to Strategic and Critical Materials: The National Defense Stockpile," Congressional Research Service, November 14, 2023, 9, https://crsreports.congress.gov/product/pdf/R/R47833.

[17] National Research Council, *Managing Materials for a Twenty-first Century Military* (Washington, DC: The National Academies Press, 2008), 15, https://doi.org/10.17226/12028.

[18] National Research Council, *Managing Materials for a Twenty-first Century Military* (Washington, DC: The National Academies Press, 2008), 126, https://doi.org/10.17226/12028.

[19] Institute for Defense Analyses, "Formal Processes for Mitigating Risks of Strategic Materials Shortfalls," March 2023, https://www.ida.org/-/media/feature/publications/f/fo/formal-processes-for-mitigating-risks-of-strategic-materials-shortfalls/d-33375.ashx.

[20] Institute for Defense Analyses, "Key Materials for High-Priority Weapon Systems, and Assessing Risks to Their Supply: A Report for the US Defense National Stockpile Center," July 31, 2008, and "Supplementary Risk Assessments: A Report for the US National Defense Stockpile Center," September 3, 2008, in US Department of Defense, "Reconfiguration of the National Defense Stockpile Report to Congress," April 2009, B-2, C-2–C-3, https://www.scribd.com/document/16483302/Reconfiguration-of-the-National-Defense-Stockpile-Report-to-Congress.

would be useful for the DoD [Department of Defense] to undertake these future assessments [on annual material usage] on a sustained basis."[21] Yet, such assessments have either not been undertaken or released publicly since.

This article focuses on the US military's material shortfall risks specifically, excluding industrial and essential civilian shortfalls, because material shortfalls affecting the military can prove decisive in war.[22] Displaying the prioritization of military shortfalls, industrial and essential civilian sectors sometimes have their material supply diverted to the military during wars.[23] As President Franklin D. Roosevelt noted in his State of the Union Address one month after the attack on Pearl Harbor, "Production for war is based on metals and raw materials—steel, copper, rubber, aluminum, zinc, tin. Greater and greater quantities of them will have to be diverted to war purposes."[24] Such a statement reflects the significance of military shortfalls over industrial and essential civilian shortfalls.

3. Methodology

To select the materials, we first gathered information on the Department of Defense's annual material consumption. The most recent and comprehensive list is from an Institute for Defense Analyses assessment in the Department of Defense's "Reconfiguration of the National Defense Stockpile Report to Congress" from April 2009, and it includes thirty-five materials.[25] From this

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[21] Institute for Defense Analyses, "Key Materials for High-Priority Weapon Systems, and Assessing Risks to Their Supply: A Report for the US Defense National Stockpile Center," July 31, 2008, in US Department of Defense, "Reconfiguration of the National Defense Stockpile Report to Congress," April 2009, B-3, https://www.scribd.com/document/16483302/Reconfiguration-of-the-National-Defense-Stockpile-Report-to-Congress.

[22] C. K. Leith, "Mineral Resources in Their International Relations," *Proceedings of the American Philosophical Society* 91, no. 1 (1947): 85, http://www.jstor.org/stable/3143128; and C. K. Leith, "Mineral Resources and Peace," *Foreign Affairs* 16, no. 3 (1938): 515–516, https://doi.org/10.2307/20028870.

[23] For example, during World War II, the Controlled Materials Plan in the United States governed the use of materials, including aluminum, copper, and steel. Robert Cuff, "Organizational Capabilities and U.S. War Production: The Controlled Materials Plan of World War II," *Business and Economic History* 19 (1990): 103, https://thebhc.org/sites/default/files/beh/BEHprint/v019/p0103-p0112.pdf.

[24] Franklin D. Roosevelt, "State of the Union Address," January 6, 1942, https://www.presidency.ucsb.edu/documents/state-the-union-address-1.

[25] Institute for Defense Analyses, "Key Materials for High-Priority Weapon Systems, and Assessing Risks to Their Supply: A Report for the US Defense National Stockpile Center," July 31, 2008, in US Department of Defense, "Reconfiguration of the National Defense Stockpile Report to Congress," April 2009, B-2, https://www.scribd.com/document/16483302/Reconfiguration-of-the-National-Defense-Stockpile-Report-to-Congress.

list, we then selected those materials deemed "critical materials" by the Department of Energy, which totaled twenty-three materials.[26]

To calculate the military's demand for these materials, we proposed three different conflict scenarios with escalating material consumption. The first conflict scenario assumes that the Department of Defense's material consumption in a US-China conflict would be at 2008 levels. The "Reconfiguration of the National Defense Stockpile Report to Congress" from April 2009 lists these consumption levels.[27] The second conflict scenario assumes that the Department of Defense's material consumption in a US-China conflict would be at estimated 2021 levels. Since the military's most recent consumption data is from 2008, we had to estimate the military's 2021 consumption. To do so, we used the Department of Defense's procurement outlays as a reference, tying the military's increase in material consumption to the real percentage increase in procurement outlays from FY2008 to FY2021. Since the Department of Defense spent $88.915 billion on procurement in FY2008[28] and $112.823 billion in constant 2008 dollars in FY2021[29]—a 27 percent increase—we assumed the military's material consumption increased by 27 percent from 2008 to 2021. The third conflict scenario simply assumes that the Department of Defense's material consumption in a US-China conflict would be 25 percent more than the estimated 2021 levels.

Risks exist in using the military's material consumption from fifteen years ago as a benchmark. At the time in 2008, the US military was focused on counterterrorism and counterinsurgency

[26] US Department of Energy, "Critical Materials Assessment 2023," July 2023, 140–141, https://www.energy.gov/sites/default/files/2023-07/doe-critical-material-assessment_07312023.pdf.
[27] Institute for Defense Analyses, "Key Materials for High-Priority Weapon Systems, and Assessing Risks to Their Supply: A Report for the US Defense National Stockpile Center," July 31, 2008, in US Department of Defense, "Reconfiguration of the National Defense Stockpile Report to Congress," April 2009, B-2, https://www.scribd.com/document/16483302/Reconfiguration-of-the-National-Defense-Stockpile-Report-to-Congress.
[28] Office of the Under Secretary of Defense (Comptroller), "National Defense Budget Estimates for FY 2008," March 2007, 9, https://comptroller.defense.gov/Portals/45/Documents/defbudget/Docs/fy2008_greenbook.pdf.
[29] Office of the Under Secretary of Defense (Comptroller), "National Defense Budget Estimates for FY 2021," April 2020, 14, https://comptroller.defense.gov/Portals/45/Documents/defbudget/fy2021/FY21_Green_Book.pdf. In constant 2021 dollars, procurement outlays in FY2021 were $141.994 billion. To convert this number to 2008 dollars, we used "Inflation Calculator," Federal Reserve Bank of Minneapolis, accessed December 13, 2023, https://www.minneapolisfed.org/about-us/monetary-policy/inflation-calculator.

operations in the Middle East, not a large-scale conventional conflict against a peer competitor.[30] Thus, the military's platforms, munitions, and material consumption in 2008 will vary from the military's platforms, munitions, and material consumption in a prospective US-China conflict.[31] Importantly, a major US-China conflict would likely shift the US economy to a wartime economy. The Congressional Budget Office noted in September 1982 about cobalt, "Clearly, a wartime economy would require significantly greater defense-related expenditures in a number of industries that use cobalt. The slated defense buildup for the 1980s will probably increase the present peacetime need for cobalt."[32] Other materials would also have higher consumption levels in a large-scale conventional conflict.[33] The 2008 consumption data do provide insight, however, as US troop levels in Iraq reached their peak in 2008; consequently, the 2008 consumption data offer the most recent numbers on the US military's material consumption amid large-scale military operations.[34]

To calculate the military's material access, we only considered the most recent US material production, which is from 2021, and National Defense Stockpile inventories, which are from September 30, 2022.[35] The US Geological Survey provides this data in its annual Mineral Commodities Summary.[36] Only considering domestically produced and stockpiled materials as supply sources differs from the government's biennial stockpile assessment, which also includes

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[30] The 2008 US National Defense Strategy prioritized threats from violent transnational extremist networks. Regarding China, the strategy says, "China is one ascendant state with the potential for competing with the United States," but it adds, "The United States welcomes the rise of a peaceful and prosperous China." See US Department of Defense, "National Defense Strategy," June 2008, https://history.defense.gov/Portals/70/Documents/nds/2008_NDS.pdf?ver=WEYyBjnf6UkNioPqfkSr3Q%3d%3d.
[31] For US military capabilities needed for counterinsurgency, see David C. Gompert et al., *War by Other Means: Building Complete and Balanced Capabilities for Counterinsurgency* (Santa Monica, CA: RAND Corporation, 2008), https://www.rand.org/pubs/monographs/MG595z2.html. For US military capabilities needed for a US-China conflict, see David A. Ochmanek, *Determining the Military Capabilities Most Needed to Counter China and Russia: A Strategy-Driven Approach* (Santa Monica, CA: RAND Corporation, 2022), https://www.rand.org/pubs/perspectives/PEA1984-1.html.
[32] Congressional Budget Office, "Cobalt: Policy Options for a Strategic Mineral," September 1982, 27, https://www.cbo.gov/sites/default/files/cbofiles/ftpdocs/51xx/doc5126/doc29-entire.pdf.
[33] For example, in 1945, E. W. Pehrson of the US Bureau of Mines said, "[T]he demands for this war overtaxed our capacity for production." E. W. Pehrson, "Our Mineral Resources and Security," *Foreign Affairs* 23, no. 4 (1945): 644, https://doi.org/10.2307/20029929.
[34] Amy Belasco, "Troop Levels in the Afghan and Iraq Wars, FY2001-FY2012: Cost and Other Potential Issues," Congressional Research Service, July 2, 2009, 9, https://sgp.fas.org/crs/natsec/R40682.pdf.
[35] US Geological Survey, *Mineral Commodities Summary 2023* (Reston, VA: US Geological Survey, 2023), https://doi.org/10.3133/mcs2023.
[36] US Geological Survey, *Mineral Commodities Summary 2023* (Reston, VA: US Geological Survey, 2023), https://doi.org/10.3133/mcs2023.

foreign supplies.[37] We made this decision to assess the United States' ability independent of foreign actors to satisfy its military's material consumption. As previous national emergencies have revealed, the United States sometimes cannot rely on foreign countries, including defense allies, for critical supplies during national emergencies.

For example, in 1940 during World War II but before US entry into the war, Canada imposed a copper export ban that included the United States, although the United States was excluded in certain situations like importing copper for Allied munitions contracts.[38] More recently, during the COVID-19 pandemic, US defense allies France and Germany imposed export restrictions on potentially life-saving personal protective equipment to the United States.[39] Furthermore, even if foreign countries do seek to supply materials to the United States in a US-China conflict, many of these countries, especially those in Asia, will face contested sea lines of communication.[40] Thus, in this article, we assume that the US military can only access materials produced and stockpiled domestically.

The shortfall quantity is calculated by first taking the Department of Defense's estimated material consumption and then subtracting the sum of US material production from 2021 and National Defense Stockpile inventories from September 2022.

Department of Defense's estimated material consumption – (US material production from 2021 + National Defense Stockpile inventories from September 2022) = Shortfall (Excess)

[37] Under Secretary of Defense for Acquisition, Technology and Logistics, "Strategic and Critical Materials 2015 Report on Stockpile Requirements," US Department of Defense, January 2015, Appendix 2-11–2-12, https://www.hsdl.org/?view&did=764766.
[38] "Canadian Action Would Cut Off Only 11% of US Imports," *New York Times*, October 10, 1940, https://www.nytimes.com/1940/10/10/archives/copper-ban-discounted-canadian-action-would-cut-off-only-11-of-us.html; and T. H. Miller, H. M. Meyer, and Allan F. Matthews, "Copper," in *Minerals Yearbook Review of 1940*, ed. H. D. Keiser (Washington, DC: US Government Printing Office, 1941), 108, https://digital.library.wisc.edu/1711.dl/NL3GAHUQMHTGL8Q.
[39] Francesco Guarascio and Philip Blenkinsop, "EU Fails to Persuade France, Germany to Lift Coronavirus Health Gear Controls," *Reuters*, March 6, 2020, https://www.reuters.com/article/us-health-coronavirus-eu-idUSKBN20T166/.
[40] Economist Intelligence Unit, "Conflict over Taiwan: Assessing Exposure in Asia," 2023, https://www.eiu.com/n/campaigns/asia-exposure-to-a-conflict-over-taiwan/.

We also calculated the military's projected material consumption as a percentage of the combined total for domestic production and stockpile inventories.

Department of Defense's estimated material consumption / (US material production from 2021 + National Defense Stockpile inventories from September 2022) = US military material consumption as a percentage of US production and stockpile

Based on this latter calculation, we assigned a shortfall risk level for each material in the below tables. If the material had a consumption percentage of 100 percent or greater when compared to both domestic production and the stockpile—that is, US military consumption for that material was greater than the combined total of the material produced and stockpiled in the United States—it was deemed high risk and highlighted as red. If the material had a consumption percentage of less than 100 percent but greater than 50 percent when compared to the combined total of the domestic production and stockpile, it was deemed medium risk and highlighted as orange. If the material had a consumption percentage of less than 50 percent but greater than 0 percent when compared to the combined total of the domestic production and stockpile, it was deemed low risk and highlighted as yellow.

4. Results

We found that at 2008 material consumption levels, the US military has a high shortfall risk for six materials, a medium shortfall risk for three materials, and a low shortfall risk for fourteen materials (Table 1).

Table 1: Material shortfall risks for the US military based on 2008 material consumption levels.

Material	2008 DOD Consumption[1] (metric tons)[2]	2021 US Production[3] (metric tons)	Stockpile as of September 30, 2022[3] (metric tons)	Estimated DOD Consumption as Percentage of US Production and Stockpile	Shortfall (Excess) (metric tons)
Aluminum metal	249,746	4,189,000	-	6%	(3,939,254)
Antimony	4,259	4,629	90.16	90%	(460)
Bismuth	156	80.0	-	195%	75.6
Ferrochromium	8,773	–[a]	43,800	20%	(35,027)
Chromium metal	829	–[a]	3,470	24%	(2,641)
Cobalt	3,850	2,450	316	139%	1,084
Niobium (Columbium)	440	-	554	79%	(114)
Copper, refined	95,849	971,000	-	10%	(875,151)
Fluorspar, metallurgical grade	2,257	–[b]	-	∞	2,257
Fluorspar, acid grade	51,311	40,000	-	128%	11,311
Iridium	0.272	-	0.015	1815%	0.26
Ferromanganese	7,166	9,000[c]	104,000	6%	(105,834)
Manganese ore, metallurgical grade	22,724	-	291,000	8%	(268,276)
Nickel	15,709	18,400[d]	759	82%	(3,450)
Palladium	2.087	13.70	-	15%	(11.61)
Platinum	0.726	4.02	0.261	17%	(3.56)
Silicon Carbide	8,041	35,000	-	23%	(26,959)
Tantalum	128	222[e]	92.09	41%	(186)
Tin	2,602	16,630	3,578	13%	(17,606)
Titanium sponge	7,975	500[f]	-	1595%	7,475
Tungsten	812	7,230[g]	6,005	6%	(12,423)
Vanadium	122	3,200	-	4%	(3,078)
Zinc, refined	46,357	220,000	6,460	20%	(180,103)

Sources: Institute for Defense Analyses and US Geological Survey.

[1]Sourced from "Reconfiguration of the National Defense Stockpile Report to Congress" by the Institute for Defense Analyses from April 2009.

[2]The Department of Defense's mineral consumption in listed in short tons. To convert these numbers to metric tons, they were divided by 1.102.

[3]Sourced from US Geological Survey.

[a]While the US produced an estimated 114,000 metric tons of chromium, this figure was based on "reported receipts of all types of stainless-steel scrap"—not ferrochromium or chromium metal. According to the US Geological Survey, the United States had zero capacity for ferrochromium and chromium metal production in 2021.

[b]The US Geological Survey only recorded the production of acid-grade fluorspar in the United States, although it notes, "One company sold fluorspar from stockpiles produced as a byproduct of its limestone quarrying operation in Cave-In-Rock, IL." The US Geological Survey did not record any data on the quantities produced.

[c]According to the US Geological Survey, "Manganese ferroalloys were produced at two plants," but the statistics were withheld to avoid disclosing companies' proprietary information. For a production estimate, US ferromanganese exports are used.

[d]This nickel production total only incudes mine production as the refinery byproduction production is withheld to avoid disclosing a company's proprietary information.

[e]There was no domestic mine production for tantalum, and recycled production for tantalum is unavailable. However, the US Geological Survey says the amount of recycled tantalum "may account for as much as 30% of consumption by domestic primary processors." With apparent US consumption of tantalum at 740 metric tons in 2021, 30 percent of consumption is 222 metric tons.

[f]According to the US Geological Survey, one facility Utah produced titanium sponge, but "Production data were withheld to avoid disclosing company proprietary data." However, the facilty has an estimated production capacity of 500 metric tons per year.

[g]The most recent data for tungsten production is from 2019, and it includes production of "tungsten metal powder and tungsten carbide powder produced from metal powder; excludes cast and crystalline tungsten carbide powder and chemicals."

To illustrate, the US military consumed 3,850 metric tons of cobalt in 2008, while the Department of Defense stockpiled 316 metric tons of cobalt as of September 2022 and the United States produced 2,450 metric tons of cobalt in 2021—most of which was exported outside the United States for refining. Thus, if the US military consumed the same amount of cobalt in a US-China conflict as it did in 2008, the military would have a cobalt shortfall of 1,084 metric tons, meaning the US military would have to rely on 1,084 metric tons of foreign cobalt imports to meet military demand. Given the high risks of supply chain disruption during a US-China conflict, these materials would not be a guaranteed supply source. Moreover, since the United States does not have any operating refineries for refining cobalt ores and concentrates and since cobalt ores and concentrates have no applications unless it is refined, the domestic shortfall is more accurately 1,734 metric tons, when cobalt ore is excluded as a supply source.[41] In other words, the US military will have to rely on foreign imports for 1,734 metric tons of cobalt, *if* the US military's cobalt consumption during the conflict is indeed 3,850 metric tons of cobalt. However, suppose the US military's cobalt consumption is even higher due to higher attrition rates or higher use of cobalt-intensive components such as samarium-cobalt magnets and cobalt-based superalloys in jet engines. In that case, the cobalt shortfall would be even higher, making the US military rely even more on foreign imports—and placing cobalt at an even higher shortfall risk.

We found that at estimated 2021 material consumption levels, the US military has a high shortfall risk for nine materials, a medium shortfall risk for one material, and a low shortfall risk for thirteen materials (Table 2).

[41] Kim B. Shedd, "2018 Minerals Yearbook: Cobalt [Advanced Release]," US Geological Survey, September 2022, 19.1, https://pubs.usgs.gov/myb/vol1/2018/myb1-2018-cobalt.pdf; and "AFRY Awarded Engineering Assignment for Jervois' Cobalt Refinery Project in United States," AFRY, October 6, 2023, https://afry.com/en/newsroom/press-releases/afry-awarded-engineering-assignment-jervois-cobalt-refinery-project-in.

Table 2: Material shortfall risks for the US military based on estimated 2021 material consumption levels.

Material	Estimated 2021 DOD Consumption[1] (metric tons)[2]	2021 US Production[3] (metric tons)	Stockpile as of September 30, 2022[3] (metric tons)	Estimated DOD Consumption as Percentage of US Production and Stockpile	Shortfall (Excess) (metric tons)
Aluminum metal	317,177	4,189,000	-	8%	(3,871,823)
Antimony	5,409	4,629	90.16	115%	690
Bismuth	198	80.0	-	247%	117.6
Ferrochromium	11,142	–[a]	43,800	25%	(32,658)
Chromium metal	1,053	–[a]	3,470	30%	(2,417)
Cobalt	4,890	2,450	316	177%	2,124
Niobium (Columbium)	559	-	554	101%	4.71
Copper, refined	121,728	971,000	-	13%	(849,272)
Fluorspar, metallurgical grade	2,867	–[b]	-	∞	2,867
Fluorspar, acid grade	65,165	40,000	-	163%	25,165
Iridium	0.35	-	0.015	2305%	0.33
Ferromanganese	9,101	9,000[c]	104,000	8%	(103,899)
Manganese ore, metallurgical grade	28,859	-	291,000	10%	(262,141)
Nickel	19,951	18,400[d]	759	104%	792
Palladium	2.65	13.70	-	19%	(11.05)
Platinum	0.92	4.02	0.261	22%	(3.36)
Silicon Carbide	10,212	35,000	-	29%	(24,788)
Tantalum	162	222[e]	92.09	52%	(152)
Tin	3,305	16,630	3,578	16%	(16,903)
Titanium sponge	10,128	500[f]	-	2026%	9,628
Tungsten	1,031	7,230[g]	6,005	6%	(12,204)
Vanadium	155	3,200	-	5%	(3,045)
Zinc, refined	58,873	220,000	6,460	26%	(167,587)

Sources: Institute for Defense Analyses and US Geological Survey.

[1]Sourced from "Reconfiguration of the National Defense Stockpile Report to Congress" by the Institute for Defense Analyses from April 2009.

[2]The Department of Defense's mineral consumption in listed in short tons. To convert these numbers to metric tons, they were divided by 1.102.

[3]Sourced from US Geological Survey.

[a]While the US produced an estimated 114,000 metric tons of chromium, this figure was based on "reported receipts of all types of stainless-steel scrap"—not ferrochromium or chromium metal. According to the US Geological Survey, the United States had zero capacity for ferrochromium and chromium metal production in 2021.

[b]The US Geological Survey only recorded the production of acid-grade fluorspar in the United States, although it notes, "One company sold fluorspar from stockpiles produced as a byproduct of its limestone quarrying operation in Cave-In-Rock, IL." The US Geological Survey did not record any data on the quantities produced.

[c]According to the US Geological Survey, "Manganese ferroalloys were produced at two plants," but the statistics were withheld to avoid disclosing companies' proprietary information. For a production estimate, US ferromanganese exports are used.

[d]This nickel production total only incudes mine production as the refinery byproduction production is withheld to avoid disclosing a company's proprietary information.

[e]There was no domestic mine production for tantalum, and recycled production for tantalum is unavailable. However, the US Geological Survey says the amount of recycled tantalum "may account for as much as 30% of consumption by domestic primary processors." With apparent US consumption of tantalum at 740 metric tons in 2021, 30 percent of consumption is 222 metric tons.

[f]According to the US Geological Survey, one facility Utah produced titanium sponge, but "Production data were withheld to avoid disclosing company proprietary data." However, the facilty has an estimated production capacity of 500 metric tons per year.

[g]The most recent data for tungsten production is from 2019, and it includes production of "tungsten metal powder and tungsten carbide powder produced from metal powder; excludes cast and crystalline tungsten carbide powder and chemicals."

We found that with a 25 percent increase to estimated 2021 material consumption levels, the US military also has a high risk of shortfall for nine materials, a medium shortfall risk for one material, and a low shortfall risk for thirteen materials (Table 3).

Table 3: Material shortfall risks for the US military based on a 25 percent increase to estimated 2021 material consumption levels.

Material	25% Increase to Estimated 2021 DOD Consumption[1] (metric tons)[2]	2021 US Production[3] (metric tons)	Stockpile as of September 30, 2022[3] (metric tons)	Estimated DOD Consumption as Percentage of US Production and Stockpile	Shortfall (Excess) (metric tons)
Aluminum metal	396,471	4,189,000	-	9%	(3,792,529)
Antimony	6,762	4,629	90.16	143%	2,043
Bismuth	247	80.0	-	309%	167.1
Ferrochromium	13,927	–[a]	43,800	32%	(29,873)
Chromium metal	1,316	–[a]	3,470	38%	(2,154)
Cobalt	6,112	2,450	316	221%	3,346
Niobium (Columbium)	698	-	554	126%	144
Copper, refined	152,161	971,000	-	16%	(818,839)
Fluorspar, metallurgical grade	3,583	–[b]	-	∞	3,583
Fluorspar, acid grade	81,456	40,000	-	204%	41,456
Iridium	0.43	-	0.015	2881%	0.42
Ferromanganese	11,376	9,000[c]	104,000	10%	(101,624)
Manganese ore, metallurgical grade	36,074	-	291,000	12%	(254,926)
Nickel	24,939	18,400[d]	759	130%	5,780
Palladium	3.31	13.70	-	24%	(10.39)
Platinum	1.15	4.02	0.261	27%	(3.13)
Silicon Carbide	12,765	35,000	-	36%	(22,235)
Tantalum	203	222[e]	92.09	65%	(111)
Tin	4,131	16,630	3,578	20%	(16,077)
Titanium sponge	12,660	500[f]	-	2532%	12,160
Tungsten	1,289	7,230[g]	6,005	6%	(11,946)
Vanadium	194	3,200	-	6%	(3,006)
Zinc, refined	73,592	220,000	6,460	32%	(152,868)

Sources: Institute for Defense Analyses and US Geological Survey.

[1]Sourced from "Reconfiguration of the National Defense Stockpile Report to Congress" by the Institute for Defense Analyses from April 2009.

[2]The Department of Defense's mineral consumption in listed in short tons. To convert these numbers to metric tons, they were divided by 1.102.

[3]Sourced from US Geological Survey.

[a]While the US produced an estimated 114,000 metric tons of chromium, this figure was based on "reported receipts of all types of stainless-steel scrap"—not ferrochromium or chromium metal. According to the US Geological Survey, the United States had zero capacity for ferrochromium and chromium metal production in 2021.

[b]The US Geological Survey only recorded the production of acid-grade fluorspar in the United States, although it notes, "One company sold fluorspar from stockpiles produced as a byproduct of its limestone quarrying operation in Cave-In-Rock, IL." The US Geological Survey did not record any data on the quantities produced.

[c]According to the US Geological Survey, "Manganese ferroalloys were produced at two plants," but the statistics were withheld to avoid disclosing companies' proprietary information. For a production estimate, US ferromanganese exports are used.

[d]This nickel production total only incudes mine production as the refinery byproduction production is withheld to avoid disclosing a company's proprietary information.

[e]There was no domestic mine production for tantalum, and recycled production for tantalum is unavailable. However, the US Geological Survey says the amount of recycled tantalum "may account for as much as 30% of consumption by domestic primary processors." With apparent US consumption of tantalum at 740 metric tons in 2021, 30 percent of consumption is 222 metric tons.

[f]According to the US Geological Survey, one facility Utah produced titanium sponge, but "Production data were withheld to avoid disclosing company proprietary data." However, the facilty has an estimated production capacity of 500 metric tons per year.

[g]The most recent data for tungsten production is from 2019, and it includes production of "tungsten metal powder and tungsten carbide powder produced from metal powder; excludes cast and crystalline tungsten carbide powder and chemicals."

Since one can assume that the US military's material consumption during a large-scale conventional US-China conflict in the future will be greater than the US military's material consumption during counterterrorism and counterinsurgency operations in 2008,[42] we can assume

[42] For example, US-China war games conducted by the Center for Strategic and International Studies found that the US military generally used about 5,000 long-range missiles in the first three weeks of conflict. Mark F. Cancian, Matthew Cancian, and Eric Heginbotham, "The First Battle of the Next War Wargaming a Chinese Invasion of

that the second and third conflict scenarios better illustrate potential US military material consumption during a US-China conflict and thus potential US military material shortfalls during a US-China conflict. Both the second and third conflict scenarios found that the following nine materials have the highest shortfall risk: antimony, bismuth, cobalt, niobium (columbium), metallurgical-grade fluorspar, acid-grade fluorspar, iridium, nickel, and titanium sponge.

5. Discussion

The greatest downside risk to the government publicly releasing projected military shortfall quantities for individual materials during a conflict would be enabling foreign adversaries to better understand the US government's conflict assumptions and supply chain weaknesses, which would enable adversaries to both better prepare for conflict with the United States and undermine US material supply chains.[43] However, given the low classification level of the biennial stockpile assessment ("official government business"),[44] the US government seems to view control of such information as not vital to US national security, or possibly that US adversaries already understand such information. Furthermore, the government's seemingly low concern about releasing material shortfall projections is illustrated by the public availability of the Department of Defense's 2015 biennial stockpile assessment,[45] and the government's seemingly low concern about releasing the military's annual material usage is illustrated by the public availability of the Department of Defense's "Reconfiguration of the National Defense Stockpile Report to Congress" from 2009.[46]

Yet, current government practices on releasing information should not be considered best practice. In a 1949 study on "The Domestic Mining Industry of the United States in World War II," John D.

Taiwan," Center for Strategic and International Studies, January 2023, 136, https://csis-website-prod.s3.amazonaws.com/s3fs-public/publication/230109_Cancian_FirstBattle_NextWar.pdf?WdEUwJYWIySMPIr3ivhFolxC_gZQuSOQ.

[43] John D. Morgan, Jr., "The Domestic Mining Industry of the United States in World War II: A Critical Study of the Economic Mobilization of the Mineral Base of National Power" (PhD dissertation, Pennsylvania State College, 1949), 358–366, https://scholarsphere.psu.edu/resources/f6527d5d-8bc0-4c98-8c7d-4a21b0a69685.

[44] Defense Logistics Agency, email message to author, December 1, 2023.

[45] Under Secretary of Defense for Acquisition, Technology and Logistics, "Strategic and Critical Materials 2015 Report on Stockpile Requirements," US Department of Defense, January 2015, https://www.hsdl.org/?view&did=764766.

[46] Institute for Defense Analyses, "Key Materials for High-Priority Weapon Systems, and Assessing Risks to Their Supply: A Report for the US Defense National Stockpile Center," July 31, 2008, in US Department of Defense, "Reconfiguration of the National Defense Stockpile Report to Congress," April 2009, B-2, https://www.scribd.com/document/16483302/Reconfiguration-of-the-National-Defense-Stockpile-Report-to-Congress.

Morgan, Jr., who would later become special assistant to the assistant director for materials in the Office of the Defense Mobilization, wrote that the US government releases too much information on its mineral industry, specifically engineering and technical information.[47] But, he also said, "For an industry mobilization plan to be effective it must be known to the industry years in advance of actual fighting."[48] Thus, the main benefit of releasing information on material shortfalls is helping the defense industrial base better prepare for conflict, while the main risk of releasing such information is helping American adversaries better understand US supply chain weaknesses, which adversaries can then target.

American adversaries, especially China, however, already seem to understand US supply chain weaknesses. Chinese Communist Party outlets openly highlight US supply chain weaknesses, like in rare earths.[49] Furthermore, China is the largest US import source for gallium, germanium, and graphite,[50] and it has imposed export controls on gallium, germanium, and graphite.[51] Therefore, the risk of adversaries understanding US supply chain weaknesses has become a reality. On the other hand, the defense industrial base is still unprepared for conflict,[52] although it is increasingly aware of possible shortages in end-use defense goods, such as platforms and munitions.[53] Yet, the defense industrial base seems largely unaware of the possible shortfall

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47 John D. Morgan, Jr., "The Domestic Mining Industry of the United States in World War II: A Critical Study of the Economic Mobilization of the Mineral Base of National Power" (PhD dissertation, Pennsylvania State College, 1949), 358–366, https://scholarsphere.psu.edu/resources/f6527d5d-8bc0-4c98-8c7d-4a21b0a69685.

48 John D. Morgan, Jr., "The Domestic Mining Industry of the United States in World War II: A Critical Study of the Economic Mobilization of the Mineral Base of National Power" (PhD dissertation, Pennsylvania State College, 1949), 408, https://scholarsphere.psu.edu/resources/f6527d5d-8bc0-4c98-8c7d-4a21b0a69685.

49 Hu Weijia, "US Need for Rare Earths an Ace in Beijing's Hand," *Global Times*, May 16, 2019, https://www.globaltimes.cn/page/201905/1150281.shtml.

50 Brian W. Jaskula, "Gallium," US Geological Survey, January 2023, https://pubs.usgs.gov/periodicals/mcs2023/mcs2023-gallium.pdf; Amy C. Tolcin, "Germanium," US Geological Survey, January 2023, https://pubs.usgs.gov/periodicals/mcs2023/mcs2023-germanium.pdf; and Andrew A. Stewart, "Graphite (Natural)," US Geological Survey, January 2023, https://pubs.usgs.gov/periodicals/mcs2023/mcs2023-graphite.pdf.

51 "China to Restrict Exports of Chipmaking Materials As US Mulls New Curbs," *Reuters*, July 3, 2023, https://www.reuters.com/markets/commodities/china-restrict-exports-chipmaking-materials-us-mulls-new-curbs-2023-07-04/; and Siyi Liu and Dominique Patton, "China, World's Top Graphite Producer, Tightens Exports of Key Battery Material," *Reuters*, October 20, 2023, https://www.reuters.com/markets/commodities/china-ups-critical-minerals-heat-with-graphite-controls-2023-10-24/.

52 Seth G. Jones, "The US Defense Industrial Base Is Not Prepared for a Possible Conflict with China," Center for Strategic and International Studies, 2023, https://features.csis.org/preparing-the-US-industrial-base-to-deter-conflict-with-China/.

53 Marcus Weisgerber, "Raytheon Calls in Retirees to Help Restart Stinger Missile Production," *Defense One*, June 28, 2023, https://www.defenseone.com/business/2023/06/raytheon-calls-retirees-help-restart-stinger-missile-production/388067/.

quantities for individual materials necessary to build such platforms and munitions in a US-China conflict.[54] This information would benefit the defense industrial base in preparing it for a possible US-China conflict.

6. Conclusions

Moving forward, the Department of Defense should consider publicly releasing its biennial stockpile assessment. The Department of Defense should also consider releasing information on projected military shortfall quantities for individual materials, as well as information on the US military's annual usage of individual materials. With this information, US policymakers could better understand the military's supply chain risks and pursue risk mitigation policies. Furthermore, the defense industrial base could preemptively stockpile materials with high shortfall risks before the outbreak of a conflict, enabling the defense industry to better support the war effort.

In *The Scientific Monthly* in 1918, Joseph E. Pogue wrote: "Preparedness [for war]…must *anticipate* the organized use of every mineral resource essential to war, which means practically every mineral resource. This involves study, investigation, exploration, organization, and conservation-rigorous, complete, scientific—which must be inspired and guided by the government. Much has already been done; much remains. And as mineral resources in the future will be more significant in determining the balance of power among nations than they are to-day [*sic*], this problem becomes increasingly important at [*sic*] time goes on."[55] His recommendation then remains true today.

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[54] Regarding military preparedness, the public discourse's focus on end-use defense goods and neglect of material resources have historical precedents. In a 1917 article entitled "Mineral Resources in War and Their Bearing on Preparedness," Joseph E. Pogue wrote, "But even now attention is too exclusively focused on the industrial aspects of the problem of preparedness, and too little care has been devoted to the ultimate sources of the materials of war, to a study of mineral resources from a military standpoint." Joseph E. Pogue, "Mineral Resources in War and Their Bearing on Preparedness," *The Scientific Monthly* 5, no. 2 (1917): 120, http://www.jstor.org/stable/22641.

[55] Joseph E. Pogue, "Mineral Resources in War and Their Bearing on Preparedness," *The Scientific Monthly* 5, no. 2 (1917): 134, http://www.jstor.org/stable/22641