Hypersonic Strategies to Secure Rare Earth Magnet Supply Chains

An Analysis of Policy Options to Protect the Defense Industrial Base's Hypersonic Rare Earth Supply Chains from Chinese Intervention

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Image: Northrop Grumman, 2022.

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Disclaimer
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Honor Statement
On my honor as a student, I have neither given nor received aid on this assignment.

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Executive Summary

The American defense industrial base is too reliant on rare earth permanent magnet supply chains influenced by China, which has previously floated a possible trade embargo on the United States during periods of heightened tension (Sevastopulo et al., 2021). China produces over 90 percent of the world's permanent magnets, which are critical components in hypersonic weapons (Yao, 2022).

Rare earth permanent magnets are the strongest magnets in the world and are widely used in hypersonic weapons and other defense systems. This is primarily due to their ability to maintain high strength in extreme operating conditions and temperatures (First4Magnets, 2023). Hypersonic weapons require extremely durable and reliable materials to operate at speeds upward of 3,400 miles per hour (Watts et al., 2020).

The technical capabilities of these emerging weapons make them the next frontier of advanced weapons systems. Hypersonic weapons will soon be critical tools for national security because of their high maneuverability and low detectability. They are extremely difficult to defend against because of their unique flight path (Congressional Research Service, 2022). Adversaries of the United States, including Russia and China, are making significant gains in hypersonic research and development. The U.S. risks falling behind if it loses access to the critical inputs in these weapons.

Without intervention, the defense industrial base will experience significant disruptions in its hypersonic weapons supply chains if China were to impose export restrictions on rare earth permanent magnets. This would limit overall access to permanent magnets, especially at a reasonable cost. Resultantly, this would disrupt the U.S. Army's hypersonic weapons program as well as those of the broader Department of Defense.

To address these risks to rare earth permanent magnet supply chains posed by potential Chinese intervention, I consider the following policy alternatives:

1. **Stockpile Increases:** Increase Strategic Stockpiles of Permanent Magnets.
2. **Recycling Investments:** Invest in the Rare Earth Recycling Industry.
3. **Advisory Board:** Establish a Defense Industrial Base Rare Earth Advisory Board.

Each alternative was given a score of low, moderate, or high for each of the following criteria: affordability, effectiveness, administrative feasibility, and political feasibility. Each criterion is weighted equally. After analyzing the alternatives, I recommend the implementation of **Stockpile Increases.**

Under this alternative, the Defense Logistics Agency would procure the necessary amount of rare earth permanent magnets for the Army to sustain the development of its Long-Range Hypersonic Weapon (LRHW) program. The Defense Logistics Agency already operates the National Defense Stockpile, where it would store the magnets. The stockpile would serve as a strategic reserve in the event that the United States experiences reduced or loss of supply of rare earth permanent magnets.

Stockpile Increases scored moderate on affordability because of its estimated cost, which falls somewhere between $3.19 million and $4.25 million. It scored high on effectiveness because stockpiling has proven effective in ensuring access to critical materials and the Army could fully meet the demand of its hypersonic programs by stockpiling only an estimated 60,720 pounds of rare earth permanent magnets. It scored high on administrative feasibility because it requires almost no interagency coordination and the Defense Logistics Agency has significant experience in acquiring, transporting, and storing critical materials for the National Defense Stockpile. Lastly, Stockpile Increases scored high on political feasibility because the highest levels of government have made securing critical supply chains a top priority over the last two years and this alternative requires very few levels of approval.

The Defense Logistics Agency, hypersonic weapons developers, and rare earth permanent magnet manufacturers will be critical stakeholders in the implementation of this alternative and are likely highly supportive. Risks to implementation include the inability of magnet producers to immediately fulfill the stockpile's demand, lack of attention from decision-makers, and underestimating the total amount of magnets needed to sustain the stockpile. These can be mitigated through increased transparency, staggered and diversified procurement, and intentionally overestimating magnet needs.

Client Overview & Limitations

The U.S. Army is currently developing the Long-Range Hypersonic Weapon (LRHW). The LRHW will be a hypersonic boost-glide vehicle launched from a ground-based mobile launcher (Congressional Budget Office, 2023). The U.S. Army Combined Arms Support Command (CASCOM) is responsible for developing sustainment doctrines and training sustainment and logistics professionals (Combined Arms Support Command, 2021). As such, hypersonic supply chains are an area of interest to CASCOM. CASCOM has asked that the author utilize open-source information to independently identify and analyze a relevant problem statement.

This report is partly limited by classification and sensitivity issues. Hypersonic weapon specifications are highly classified and protected. The analyses in this report makes several assumptions and uses closely related programs, initiatives, and policies to evaluate the proposed alternatives based on the defined criteria and make as accurate estimations as possible. When an assumption is made, it is stated in the analysis.

Introduction

Introduction & Background

The American defense industrial base is too reliant on rare earth permanent magnet supply chains influenced by China, which has previously floated a possible trade embargo on the United States during periods of heightened tension (Sevastopulo et al., 2021). China produces over 90 percent of the world's permanent magnets, which are critical components in hypersonic weapons (Yao, 2022).

The Office of the Director of National Intelligence (ODNI) has outlined several counterintelligence risks to defense industrial base (DIB) supply chains, the most relevant to this problem statement being foreign ownership, control, and influence. The specific counterintelligence risks outlined by ODNI are reliance on "foreign nations and sole source suppliers for critical mission components" and the size of the DOD market limiting its ability to influence private industry at large (Office of the Director of National Intelligence, 2022). This is highly relevant to rare earth permanent magnet supply chains, in which China is the global leader in production.

China has quickly become the greatest strategic competitor to the United States. With this change, defense analysts are increasingly concerned about the potential consequences and vulnerabilities of American dependence on Chinese companies for critical defense materials. These concerns were most recently validated by the discovery that samarium-cobalt permanent magnets, a critical fighter jet part, were sourced from China, illuminating the Pentagon's limited supply chain visibility (Clark, 2022). Many other key supply chains go through China, including several of critical importance to U.S. national security (Tucker, 2022). If tensions between the United States and China escalate, China could choose to cut the U.S. off from access to critical defense materials. Based on current permanent magnet supply chains, this would be detrimental to national defense since many advanced weapons and communications systems are dependent on these materials.

The term "rare earths," or rare metals, refers to 17 elements on the periodic table. Understanding rare earth elements (REEs) and the process of producing them is critical foundational knowledge for understanding the rare earth magnet market, its supply chain vulnerabilities, and implications for hypersonic manufacturing. Rare earth elements are not just critical industrial inputs in the aerospace and defense sectors, but clean energy, electronics, and more as well (Natural Resources Canada, 2023).

Rare Earth Market Overview

Despite the name, rare earths are not actually rare and are rather quite "common in the Earth's crust" (Somarin, 2013). These elements are described as "rare" because they are often not concentrated in a single deposit, but are widely dispersed across the world. Rare earth elements are typically not economically viable to mine due to the high levels of upfront investment and advanced technology required. The financial barriers to entry and lack of REE clusters significantly reduce the economic incentives of mining (Lynas Rare Earths, 2021). These elements must be separated and extracted from other natural elements through expensive chemical and technical processes, further driving up the costs of mining and refining (Somarin, 2013).

The sheer cost of producing rare earth elements has made it difficult for American companies to enter the market. For example, a rare earth separation facility alone costs over $300 million (Topf, 2022). A heavy rare earth processing facility costs over $120 million (Mitchell, 2022). As a result, the United States defense industrial base has become highly dependent on supply chains that run through China for its rare earth materials. The U.S. imports 78 percent of its rare earths from China (Lee, 2022).

China's economic model can be described as authoritarian capitalism (Rudd, 2018). This model has considerable advantages in industries like rare earths, where the barriers to entry are extremely high and economic incentives are relatively low. The Chinese Communist Party essentially has full autonomy over its rare earth industry, which is primarily composed of state-owned enterprises. Recently, it has moved to consolidate three of its largest REE state-owned enterprises into one organization, which will give it even more influence over market pricing and supply (Zhou & Brooke, 2022). Meanwhile, American companies operate in a free market and are less willing to enter this industry. The U.S. defense industrial base has long prioritized supply chain efficiency over resiliency, which left room for China to become the global leader in REE production (Lopez, 2022).

High-Strength Rare Earth Permanent Magnets

High-strength rare earth permanent magnets, commonly referred to as rare earth magnets or permanent magnets, are a critical input in a wide variety of emerging and advanced technologies. Developed between 1960 and 1980, rare earth permanent magnets have become essential components in a wide range of technologies, from green technology like wind turbines and electric vehicles to defense systems like fighter jets and missiles (Hui, 2021a; Bunting Magnetics, 2022; U.S. Department of Energy, 2022).

Permanent magnets made from rare earth alloys have certain properties that make them highly valuable for defense applications, hypersonic weapons included. The primary reason that they are so important to hypersonics is because of their ability to operate in high temperatures without losing strength. This is essential for a missile that travels at a speed of at least Mach 5 (five times the speed of sound), or 3,400 miles per hour (Watts et al., 2020).

Rare earth permanent magnets are considered to be the "world's strongest magnets." Two important measures of strength when it comes to permanent magnets are remanence and coercivity. Remanence measures the strength of a permanent magnet's magnetic field, while coercivity measures its resistance to becoming demagnetized. These two measurements multiplied create the maximum energy product (MGOe) measurement (Bhutada, 2022). Table I compares the strength and operating temperatures of the four most common permanent magnets.

Table I. Comparison of Most Common Permanent Magnets.

Magnet (Grade)	Composition	Rare Earth	Maximum Energy Product (MGOe)	Max Operating Temperature
Neodymium (N42)	Neodymium, iron, boron	Yes	42	80°C
Samarium Cobalt (SmCo 2:17)	Samarium, Cobalt	Yes	28	350°C
Alnico (Alnico-5)	Iron, aluminum, nickel, cobalt	No	5.5	500°C
Ferrite (Ferrite-8)	Ceramics, iron oxide	No	3.5	180°C

Note: MGOe is the magnetic strength of a material. There are neodymium magnets that are even stronger than the N42 grade, though they are far less common (First4Magnets, 2023).

Neodymium-iron-boron (NdFeB) magnets, also known as neodymium magnets, are the most widely used rare earth permanent magnet. Samarium-cobalt (SmCo) magnets follow behind NdFeB magnets in popularity. Both neodymium and samarium-cobalt magnets have applications in defense systems, but for different reasons (Master Magnetics, 2023). Compared to SmCo magnets, NdFeB magnets are lightweight and exceptionally strong. They are the strongest permanent magnets in the world. This makes them ideal for use in small quantities, such as in the electronic and guidance systems for missiles and fighter jets (Bunting Magnetics, 2022).

At room temperature, NdFeB magnets outperform SmCo magnets in overall strength and MGOe (First4Magnets, 2023). SmCo magnets can withstand far higher operating temperatures than NdFeB magnets. At temperatures above 150 degrees Celsius, SmCo magnets outperform NdFeB magnets as they are better able to maintain "their magnetic properties over temperature changes" (Magma Magnetic Technologies, 2022). This is ideal for hypersonic weapons, which need to withstand extremely high temperatures while operating at upwards of 3,400 miles per hour (Watts et al., 2020). For example, the "leading edges" of a missile traveling at Mach 5, such as the wings and nose, reach up to 1,800 degrees Celsius. Furthermore, Mach 5 will eventually be on the slow end of hypersonic weapon speeds, as experts are already discussing future weapons that could travel at nearly Mach 20 (Keller, 2021).

Demand for permanent magnets is expected to increase significantly in the coming decade, largely driven by the green energy boom. The global market for permanent magnets was valued at $20.6 billion in 2022 and is forecasted to grow at a compound annual growth rate of 8.4 percent between 2022 and 2030 (Grand View Research, 2022). The rapid growth of the green technology market thus far has been the primary driver of increasing demand for permanent magnets (Shadaab et al., 2021). The Department of Defense has been requesting more money each year for hypersonic research and development, which will very likely further drive up global demand for permanent magnets (Losey, 2022).

Hypersonic Weapons

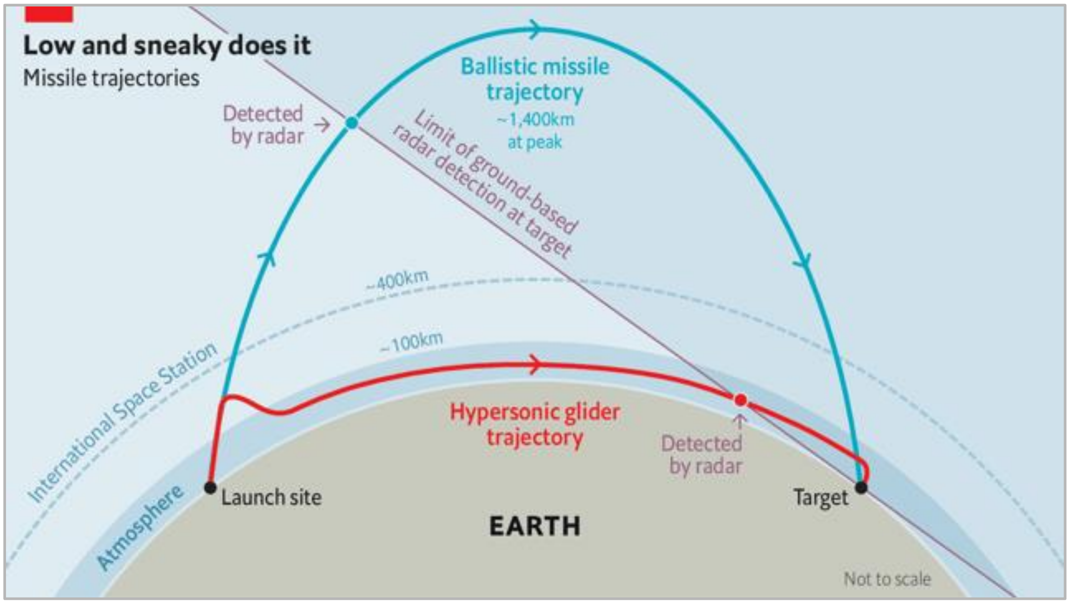
Hypersonic weapons are munitions that fly at the speed of Mach 5 or higher. Generally, hypersonic weapons can be categorized into two main groups: hypersonic cruise missiles and hypersonic glide vehicles.

- **Hypersonic Cruise Missiles (HCMs)** are boosted to hypersonic or near-hypersonic speeds using a rocket and then utilize a supersonic combustion ramjet (scramjet) air-breathing engine to gain and maintain speed. HCMs operate at extremely low altitudes, typically less than 100 meters, until reaching their target (Congressional Budget Office, 2023).

- **Hypersonic Glide Vehicles (HGVs)** are initially boosted by a rocket up into space on the same trajectory as a traditional ballistic missile until they detach from their booster. Once the glide vehicle is released from the booster, it re-enters the atmosphere and glides to its target at hypersonic speeds (Zastrow, 2021).

Hypersonic weapons do not necessarily reach their target faster than a traditional inter-continental ballistic missile (Hollings, 2022). Rather, the main advantage is that they are significantly more difficult to defend against as they are highly maneuverable after being released from their rocket boosters. Even if a missile defense system is able to detect a hypersonic weapon and activate countermeasures, the chance of interception or disablement is low because of its high maneuverability. This contrasts with traditional ballistic missiles, which are not maneuverable and follow a more predictable path. The comparatively low flight altitude of hypersonic weapons increases the difficulty of missile defense. Ground-based missile radars can detect and respond to traditional ballistic missiles earlier than hypersonic weapons, as they reach far higher altitudes (Congressional Research Service, 2022). Figure 1 illustrates the differences in trajectory and detection abilities.

Figure 1. Trajectories of Ballistic Missiles Compared to Hypersonic Gliders.



(The Economist, 2019)

Hypersonic weapons provide significant technical advantages to traditional ballistic missiles. Both can be armed with nuclear warheads, but hypersonics are better able to evade detection and countermeasures (Congressional Research Service, 2022). The Department of Defense is investing significantly in hypersonic weapons research to capitalize on its strategic advantages. Those funding levels are only expected to increase, especially as adversarial hypersonic programs continue to advance, particularly those of Russia and China. The Pentagon requested a $4.7 billion budget for hypersonics research in FY2023, a significant increase from the $3.8 billion it requested for FY2022 (Sayler, 2023). As funding for hypersonics increases, so too does concern about supply chain security of critical inputs in these weapons, such as rare earth permanent magnets.

Permanent Magnet Supply Chains

The supply chain for rare earth permanent magnets is essentially the same regardless of whether they are NdFeB or SmCo magnets.

1. **Mining:** Ore containing large quantities of rare earth elements is mined from massive deposits across the world (Electron Energy Corporation, 2022). REEs are abundant in the earth's crust, but they are often found mixed with other compounds (Somarin, 2013). While the United States comes second in global mining production of rare earth elements, China dominates the market with 63 percent of global mining output (Pistilli, 2023; Yao, 2022).

2. **Extraction:** Once the raw materials are mined, a mixed compound must be extracted from the ore (Electron Energy Corporation, 2022). This process involves the use of chemicals to disintegrate parts of the ore in order to recover high amounts of rare earth mixed compounds (Metso Outotec, 2023).

3. **Separation:** After extraction, the mixed compounds need to be separated into individual rare earth oxides before they can be processed (Electron Energy Corporation, 2022). This is done through a process called calcination, where the mixed compounds are heated at high temperatures to remove impurities and/or oxidize the metals. This produces a more purified substance (Ray, 2021)

4. **Processing:** Once a rare earth oxide has been produced, it can then be processed into a rare earth metal for use in final products, such as NdFeB and SmCo magnets (Electron Energy Corporation, 2022). China accounts for 85 percent of the world's supply of processed rare earths (Yao, 2022).

5. **Permanent Magnets:** Lastly, rare earth metals can be manufactured into NdFeB and SmCo permanent magnets. The strongest magnets are processed a second time through a method called sintering, where fine rare earth powder is pressed into a solid. Sintered magnets are stronger and smaller than bonded magnets, providing significant advantages in defense applications (Stanford Magnets, 2023). China produces over 90 percent of the world's permanent magnets (Yao, 2022).

All of the steps in the permanent magnet supply chain are extremely costly, partly due to the material and labor costs being far less in China than in the United States. The unique technical challenges at each phase of the supply chain also drive up the cost. For example, there is a large gap in intellectual property rights for NdFeB magnets between the United States and both China and Japan, the first and second largest magnet manufacturers respectively. Between 2001 and 2021, Japan applied for 855 NdFeB patents, China for 137, and the United States for only 81. As a result, the U.S. has no choice but to put forth significant upfront investment for research and development, as each step of the supply chain requires highly advanced technologies and scientific processes (Smith et al., 2021).

The United States once had a complete end-to-end domestic permanent magnet supply chain, which it is currently taking steps to rebuild. However, even with the experience and technical know-how, that is not achievable within a short timeframe (Subin, 2021). China is currently the only country that has the capability to carry out every step of the permanent magnet supply chain (The White House, 2021b). Table II compares American and Chinese permanent magnet supply chains.

Table II. Comparative Analysis of U.S.-China NdFeB Magnet Supply Chains.

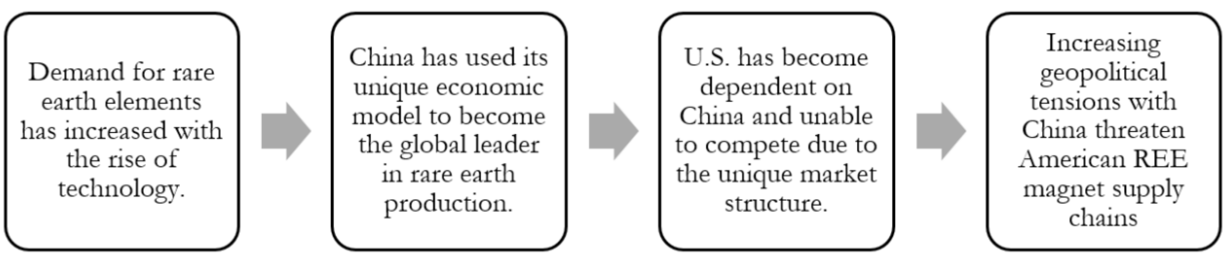
Country	Mining (Ore)	Extraction (Mixed Compounds)	Separation (Oxides)	Processing (Metals)	Permanent Magnets
China	✓	✓	✓	✓	✓
USA	✓	**	**	Idle	**

This table utilizes data from the White House's 2021 report on building resilient supply chains. ✓ denotes active capacity. ** denotes ongoing work to re-establish capacity" (Hui, 2021b)

Potential Consequences

In times of geopolitical tension, China has threatened to ban exports of rare earth elements to major American defense contractors, such as Lockheed Martin, Boeing, and Raytheon (Reichman, 2019; Sevastopulo et al., 2021). These firms are major manufacturers of hypersonics for the U.S. Department of Defense. China has previously banned rare earth exports to Japan, an ally of the United States (Bradsher, 2010). Figure 2 illustrates a theory of how China has come to dominate the global rare earth and permanent magnet markets and why this is a concern for the United States.

Figure 2. Theory of Change.



If China decided to ban rare earth exports to the United States, the American defense industrial base would most likely substitute those elements with alternatives, which are far less effective in defense applications (Hurst, 2010). The costs would be reductions in both national security and relative military power. U.S. hypersonic research and production would stall, while China's would continue to progress. Resultantly, the United States would see a reduction in relative geopolitical power as its hypersonic capabilities fall behind its adversaries.

The opportunity costs of American REE dependence on China are more quantifiable than direct costs within the national security context. For example, the U.S. Department of Energy announced a $30 million program to secure the American rare earth supply chains that are relevant to batteries and electric vehicles (Subin, 2021). This money could have been spent on another initiative if securing rare earth supply chains was not such a major concern.

Policy Landscape

U.S. reliance on Chinese permanent magnets has recently been a dominating topic of discussion in the defense community, which has been pursuing policies to mitigate risks to this critical supply chain. The primary efforts of the DOD and US Government have largely been focused on 1) re-establishing domestic capacity at every step of the supply chain and 2) investing in the research and development of alternatives to SmCo and NdFeB magnets.

There is ongoing work to re-establish rare earth extraction, separation, and magnet production capacity in the United States (The White House, 2021b). Since 2017, MP Materials, an American rare earth metals company, acquired Mountain Pass mine in California and resumed rare earth mining operations. In 2020, the DOD invested $10 million into the development of MP Materials' rare earth refinement facility, which is not yet operational. In 2022, the DOD awarded MP Materials a $35 million contract to construct a rare earth processing facility at its Mountain Pass site. The company even began construction of a permanent magnet factory in April 2022. These pursuits have a limited ability to address U.S. reliance on Chinese permanent magnets in the short term. While the U.S. is on track to eventually re-establish a full permanent magnet supply chain, the research, development, construction, and testing of the facilities needed at each phase of the supply chain takes years (Easley, 2023).

The development of rare earth permanent magnet alternatives could significantly reduce the defense industrial base's reliance on foreign production. The Departments of Defense and Energy have been heavily involved in the research and development of such alternatives (Hurst, 2010; U.S. Department of Energy, 2021). The US Government has also engaged several public universities to research alternatives that could completely or partially replace NdFeB and SmCo magnets. These alternatives would not rely solely on rare earths and would be similar in strength. The U.S. Department of Energy's Ames Laboratory, the University of Nebraska, and the University of Delaware have all been involved in research on this topic (Hurst, 2010).

The Defense Advanced Research Projects Agency (DARPA) is currently researching alternative mining methods called biomining. If successful, the initiative, called EMBER, would be a new and more efficient method of separating and processing rare earth compounds. This would account for two steps of the permanent magnet supply chain, further increasing its resilience (Easley, 2023).

There are limitations to initiatives to research and develop alternatives to various steps of the magnet supply chain, namely that there is no guarantee of a scientific breakthrough. It is impossible to know for certain if this experimental research will yield any significant innovations, specifically being able to replicate the efficiencies of neodymium and samarium in high-temperature resistant permanent magnets. It is highly possible that the research will not lead to any innovations. Lastly, most of this research was taking place around 2010 and 2011, which was over 10 years ago (Hurst, 2010). It is not yet fully clear what the impact, if any, of this research has been.

Most of the US Government's efforts to address vulnerabilities in the permanent magnet supply chain are focused on the long term. Without policies to address supply chain risks in the short term, the defense industrial base is more exposed to potential malign Chinese intervention.

Policy Analysis

This section will focus on policy alternatives to address the vulnerabilities in U.S. permanent magnet supply chains with hypersonic applications. It will start with a description of the criteria that will be used to evaluate each alternative, then a detailed description of the proposed alternatives, an analysis of each alternative based on the evaluative criteria, and finally, an outcomes matrix and final recommendation

Evaluative Criteria

To reduce Chinese influence on the American high-strength permanent magnet supply chain, the United States Army Combined Arms Support Command could pursue the following policy alternatives in collaboration with the broader Department of Defense community:

1. **Stockpile Increases:** Increase Strategic Stockpiles of Permanent Magnets.
2. **Recycling Investments:** Invest in the Rare Earth Recycling Industry.
3. **Advisory Board:** Establish a Defense Industrial Base Rare Earth Advisory Board.

The proposed policy alternatives above will be evaluated by a set of criteria defined in this section. The goal of this evaluation is to provide the most accurate forecast of outcomes and impacts should the U.S. Army Combined Arms Support Command decide to pursue any of these alternatives. Each criterion has been selected based on its relevance to CASCOM's objective of **working with the broader Department of Defense community** to strengthen the defense industrial base permanent magnet supply chains so that hypersonic weapons development can continue with as little disruption as possible. The criteria that will be used for evaluation are as follows:

1. **Affordability**
2. **Effectiveness**
3. **Administrative Feasibility**
4. **Political Feasibility**

Each criterion will be used to individually evaluate each alternative. Each alternative will receive a score of low, moderate, and high based on how well its project outcome performs under each criterion. An overall score will then be generated for each alternative based on the combined individual criterion ratings.

Evaluative criteria will be used to project the outcomes of each alternative and determine which options would be the most effective at addressing the problem statement within the predefined constraints and specific objectives. The criteria are described in detail below.

Affordability

Affordability will only measure the total estimated financial cost of an alternative. It will consider the upfront costs of a program. This criterion will be based on government, industry, and think tank estimates. It will also consider the costs of programs that are similar to the proposed alternative but in different policy areas. For example, a technology advisory board likely has the same financial costs as a rare earth advisory board. The cost ranges used in this criterion were selected based on the general range in costs of various policy alternatives in adjacent critical supply chain issue areas.

Affordability	
Low	The alternative has a comparatively high monetary cost. The alternative will receive a score of low (1) if the estimated cost is **greater than $10 million.**
Moderate	The alternative has a comparatively moderate monetary cost. The alternative will receive a score of moderate (2) if the estimated cost is **more than $1 million and less than $10 million.**
High	The alternative has a comparatively low monetary cost. The alternative will receive a score of high (3) if the estimated cost is **less than $1 million.**

Effectiveness

Effectiveness will measure the degree to which a policy alternative increases the resilience of American rare earth permanent magnet supply chains. It will consider how well an alternative prepares the US Government and defense industrial base for a possible event where China restricts rare earth permanent magnet exports to the United States. This rating only gauges the effectiveness in the short-term (up to the year 2030) because of current efforts to establish domestic processing and production capacity of rare earth permanent magnets by around that time. This criterion will be based primarily on information sourced from published research studies.

Effectiveness	
Low	The alternative **does not at all or minimally prepares** American hypersonic weapons developers for possible Chinese bans or restrictions on permanent magnet exports to the United States. These companies would experience significant disruption in their operations. It will either have no impact at all on hypersonic supply chains or a tangible impact only **after four years** from the start of implementation.

Moderate	The alternative **somewhat prepares** American hypersonic weapons developers for possible Chinese bans or restrictions on permanent magnet exports to the United States. Hypersonic developers could continue operations, although with moderate disruption. It will have a tangible impact on hypersonic supply chains within **two to four years** from the start of implementation.
High	The alternative **adequately prepares** the defense industrial base to maintain hypersonic weapons development with minimal or nonexistent disruption if China were to ban or restrict permanent magnet exports to American defense companies. It will have a tangible impact on hypersonic supply chains within **zero to two years** from the start of implementation.

Administrative Feasibility

Administrative feasibility will measure the degree to which a proposed alternative can be easily implemented regardless of cost or other factors. This criterion will consider the number of agencies that will be involved in the implementation process, the levels of approval needed, and the government's experience implementing similar policies. This data will primarily be sourced from news media and official government websites and statements.

Administrative Feasibility	
Low	The alternative will require a **significant** degree of interagency coordination. Its implementation will involve a significant number of stakeholders both within and outside the government. The implementing organization has **little or no experience** implementing similar policies.
Moderate	The alternative will require a **moderate** degree of interagency coordination. Its implementation will involve a few stakeholders both within and outside the government. The implementing organization has **some experience** implementing similar policies.
High	The alternative will require **little or no** interagency coordination. Its implementation will depend almost entirely only on government stakeholders. The implementing organization has **significant experience** implementing similar policies.

Political Feasibility

Political feasibility will consider the likelihood that a proposed alternative will receive the necessary approvals to be implemented from the appropriate government officials. This measure will consider the views and opinions of government officials or organizations that need to approve the alternative. It will largely look at whether or not the implementing organizations have taken public stances on the alternative. It will also consider whether or not the government has previously implemented similar policies to address the defense industrial base's reliance on Chinese permanent magnets. This data will primarily be sourced from news articles and official statements or press releases.

Political Feasibility	
Low	The alternative or closely related alternatives have received **little to no public support** from relevant government decision-makers. The government has not implemented any policies that are similar to the alternative to address the same problem or other closely related problems.
Moderate	The alternative or closely related alternatives have received **some public support** from relevant government decision-makers. The government has implemented some policies that are similar to the alternative to address the same problem or other closely related problems.
High	The alternative or closely related alternatives have received **significant public support** from relevant government decision-makers. The government has implemented many policies that are similar to the alternative to address the same problem or other closely related problems.

Alternatives & Evaluation

Alternative I: Increase Strategic Stockpiles of Permanent Magnets

The United States Government maintains strategic stockpiles of critical items, including medical equipment, pharmaceuticals, petroleum, and much more (Siripurapu, 2022). The Defense Logistics Agency (DLA) is responsible for the "operation and oversight of the National Defense Stockpile," which includes the rare earth elements and other critical inputs in advanced defense systems such as hypersonics (Defense Logistics Agency, 2023a).

Between 1952 and today, the value of the strategic mineral stockpile has dropped from $42 billion to less than $900 million, largely due to Congressionally authorized sell-offs. Much of this stockpile comprises lithium, cobalt, and other raw metals—including rare earths (Harris, 2022). Very little, if any, of the stockpile's inventory includes high-strength rare earth permanent magnets. China is by far the global leader in the processing of rare earths and the production of these magnets (Yao, 2022).

The United States does not have the domestic capability to refine and process rare earth elements. As a result, American weapons systems are almost entirely reliant on China for rare earth components (Johnson & Seligman, 2019). To address this foreign dependence, the Defense Logistics Agency should begin expanding the national stockpile of high-strength permanent magnets. The DLA operates stockpiles across the country and could store the magnets at any number of locations. The U.S. is making significant efforts to establish a domestic end-to-end production capability of these magnets, though it takes years to establish a capability at each level of the supply chain (Hui, 2021b). A larger stockpile would serve as a form of insurance in the short term that could later be sold off when not needed anymore.

Besides China, there are several countries where the Defense Logistics Agency could procure these magnets. Japan, the Philippines, and Germany produce a combined 18 percent of American imports of sintered neodymium magnets (Palmer, 2022). The DLA has a dedicated annual budget for National Defense Stockpile procurements that it could use to purchase these magnets. The Senate also moved to give the DLA more flexibility over that fund in the most recent National Defense Authorization Act (Harris, 2022). The total cost will vary highly depending on several factors, such as the country the magnets are being procured from, the type of magnet, and the total purchase size.

There are significant challenges to evaluating this policy alternative with open-source information due to government sensitivities. There is little information covering the specifics of what is already included in the National Defense Stockpile and the Defense Logistics Agency's plans. For example, in 2019, the Department of Defense was seeking proposals to store a six-month rotating supply of NdFeB, or neodymium iron boron, magnets (Scheyder, 2019). Since then, there have been no public updates on the program. However, an October 2022 Congressional Research Service report detailed how a section of the proposed Fiscal Year 2023 National Defense Authorization Act "would mandate stockpiling rare earth permanent magnets for defense needs," indicating that it is highly unlikely that a stockpile has been established yet (Nicastro & Tilghman, 2022).

On the implementation side, it might be challenging to purchase much larger than normal quantities of high-strength rare earth magnets at once. The smaller producers of the magnets (Japan, the Philippines, and Germany) may not have the capacity to immediately supply a cache of magnets that could fulfill U.S. stockpile demand.

Evaluation: Stockpile Increases

Affordability: Moderate

Stockpile Increases received a score of **moderate** in the affordability category. This is primarily due to the somewhat high upfront costs of establishing a stockpile of rare earth permanent magnets. The Defense Logistics Agency would be responsible for maintaining the magnet stockpile and already operates 17 distribution centers in the continental United States and nearly 10 more outside the continental United States (Defense Logistics Agency, 2023b). Several of these distribution centers have less than 50 percent utilization and could be used for the magnet stockpile, thus eliminating the need to build a new facility (Reece, 2021). This drives the affordability score up. Therefore, the primary costs of establishing a rare earth magnet stockpile come from the purchase price of the materials.

Due to classification issues, there is no public data on the exact amount of rare earths used in the LRHW, so the F-35 fighter jet will serve as a benchmark. The F-35 Lightning II contains approximately 920 pounds of rare earth metals (Grasso, 2013). Curb weight is an important factor influencing the level of rare earth metals used in a defense system. The F-35 weighs approximately 29,300 pounds, which is 13,000 pounds more than the 16,300-pound weight estimation of the U.S. Army's Long Range Hypersonic Weapon (Royal Australian Air Force, 2023; Trevithick, 2021). The F-35 can operate at both high speeds (Mach 1.6) and altitude (50,000 feet) while maintaining a high degree of maneuverability (Royal Air Force, 2023). These characteristics are similar to that of a hypersonic weapon. While the F-35 can reach a similar altitude as the LRHW, the LRHW travels nearly more than three times as fast at a speed of Mach 5 (Feickert, 2023). The more extreme operating conditions that the LRHW must endure compared to the F-35 means that both likely use a similar amount of rare earth magnets despite the high weight disparity. A major advantage of permanent magnets is the extreme conditions they can operate (Magma Magnetic Technologies, 2022).

It has been publicly confirmed that SmCo magnets are an input in the F-35 (Grazier, 2022). Hypersonic weapons likely use more SmCo magnets than NdFeB magnets given their ability to withstand higher temperatures and therefore higher speeds (Magma Magnetic Technologies, 2022). Therefore, this analysis will assume that on the low end, at least 50 percent of the permanent magnets in the LRHW are SmCo, while the remaining 50 percent are NdFeB. It will also assume that on the high end, at most 100 percent of the permanent magnets in the LRHW are SmCo, while 0 percent are NdFeB. These numbers can be altered and calculations adjusted. SmCo magnets cost approximately $70 per pound, while NdFeB magnets cost approximately $35 per pound (China Magnets Source, 2023). Tables III and IV below provide the minimum and maximum cost estimates of permanent magnets per LRHW unit.

Table III. Estimated Permanent Magnet Cost Per LRHW at a 50:50 SmCo to NdFeB Ratio.

Rare Earth Magnet	Price Per Pound	Weight of Magnet Type Per LRHW	Total Cost by Magnet Type	Total Magnet Cost Per Unit
SmCo	$70	920 * 0.50 = 460 lbs	$70 * 460 lbs = $32,200	**$48,300**
NdFeB	$35	920 * 0.50 = 460 lbs	$35 * 460 lbs = $16,100	

Table IV. Estimated Permanent Magnet Cost Per LRHW at a 100:0 SmCo to NdFeB Ratio.

Rare Earth Magnet	Price Per Pound	Weight of Magnet Type Per LRHW	Total Cost by Magnet Type	Total Magnet Cost Per Unit
SmCo	$70	920 * 1.00 = 920 lbs	$70 * 920 lbs = $64,400	**$64,400**
NdFeB	$35	920 * 0.00 = 0 lbs	$35 * 0 lbs = $0	

At this time, the United States Army reportedly plans to acquire 66 LRHWs (Congressional Budget Office, 2023). This would bring the total estimated cost of acquiring sufficient permanent magnets **between $3,187,800 and $4,250,400.** Both the low and high-cost estimates of this alternative fall within the **moderate** affordability range.

<u>Effectiveness: High</u>

Increasing the amount of rare earth permanent magnets in the National Defense Stockpile (NDS) receives a rating of **high.** Stockpiles in general have proven time and time again to be a highly effective strategy for guaranteeing access to critical goods that could be susceptible to shortages. The US Government maintains national stockpiles of petroleum, medical equipment, pharmaceuticals, and even ore that contains rare earths because of their ability to effectively mitigate the impact of a critical shortage (Siripurapu, 2022). The effectiveness of this alternative receives a high score in part due to what is happening in the status quo. There are ongoing efforts to establish a domestic production capacity of permanent magnets in the United States (Hui, 2021b). These efforts make this alternative a fairly effective short-term option to address potential Chinese export restrictions on permanent magnets.

Based on the calculations and assumptions above in the Affordability section, the Defense Logistics Agency would need to add 920 pounds per LRHW to the National Defense Stockpile to fulfill the program's demand. Since the Army currently plans to acquire 66 LRHWs, this brings the total needed magnet supply to **60,720 pounds** (Congressional Budget Office, 2023). The current market size volume of the global rare earth permanent magnet market is nearly 1,180 kilotons, which significantly exceeds the approximately 30-ton demand (Grand View Research, 2022). Stockpiling this amount would completely fulfill the LRHW program's magnet demand, significantly improving the resilience of the Army's hypersonic permanent magnet supply chain. The Army would be much better equipped to continue with the development of the LRHW and weather potential Chinese export restrictions until an end-to-end domestic production capacity is established.

Administrative Feasibility: High

Stockpile Increases scored **high** on the administrative feasibility criterion. There are very few barriers to the implementation of this alternative. The Defense Logistics Agency is highly experienced in acquiring, transporting, and storing critical materials for the National Defense Stockpile. It is one of the primary responsibilities of the agency. The DLA should have no trouble applying their expertise and experience to permanent magnets. The National Defense Stockpile also has a transaction account worth approximately $500 million that it is authorized to spend on acquiring critical materials, further easing the implementation of this alternative (USAspending, 2023). As such, the DLA will be the only implementing organization and this alternative will require almost no inter-agency coordination.

Political Feasibility: High

Stockpile Increases is rated **high** on political feasibility. This rating is driven largely by the significant efforts already taken at the Office of the President and Office of the Secretary of Commerce to create a robust neodymium-iron-boron (NdFeB) permanent magnet industry to reduce reliance on China. NdFeB magnets are the most widely used form of rare earth permanent magnets and are critical inputs in a wide variety of defense systems. This includes actions taken by the Department of Defense, which has invested "$200 million to increase domestic rare earth separation capacity" (U.S. Department of Commerce, 2022). Considering these factors, this alternative will likely have very few hurdles to obtaining the necessary approvals for implementation. Stockpiling has long been a strategy of the government to reduce supply chain vulnerabilities, indicating that this alternative would likely be highly politically feasible (Siripurapu, 2022).

Alternative II: Invest in the Development of a Rare Earth Recycling Plant

Manufacturing with rare earth elements is a relatively new but up-and-coming field. As such, most of the rare earth elements in a given end unit are newly mined and processed as opposed to recycled. As this form of manufacturing continues to develop over the years, there will be more and more used technology that could be recycled (Cammarata, 2022). This presents a large opportunity for the defense industry to reduce its reliance on China and expand domestic production of high-strength magnets.

The same rare earth elements that are used in high-strength magnets are also used in a wide array of other technologies, such as computers, vehicles, batteries, wind turbines, and more. Researchers have estimated that the effective recycling of these items could meet more than 20 percent of the demand for rare earths by 2030. As newer technologies like electric vehicles and wind turbines, which happen to have high concentrations of rare earths, meet their end-of-life, the effect of recycling will compound (Marshall, 2014).

The U.S. Department of Defense has invested in the rare earth industry before, to the tune of hundreds of millions of dollars (U.S. Department of Defense, 2022). The Department should award another contract to develop a commercial-scale rare earth recycling plant in support of Executive Order 14017, which aims to strengthen American supply chains (The White House, 2021a).

Implementation of this alternative may prove difficult because of the challenges in the recycling process itself. End items with large concentrations of rare earths like turbines and electric vehicles are yet to be recycled because of their long lifespans and relative newness. Consumer electronics contain rare earths, however, they are often highly dispersed throughout the device making the recycling process even more costly (Marshall, 2014). It is possible that a commercial-scale rare earth recycling facility would have trouble maintaining profitability by only recycling consumer electronics.

Evaluation: Recycling Investments

<u>Affordability: Low</u>

Recycling Investments scored **low** on affordability. Rare earth recycling plants are extremely expensive to build because of the immense upfront capital required and the advanced technology necessary to separate rare earth magnets from recycled end items. The total cost of a facility that recycles scrap alloy to produce permanent magnets is approximately $100 million. This number is based on the $100 million estimated upfront cost of JL MAG Rare-Earth's recently-announced plans to construct a rare earth recycling and permanent magnet manufacturing facility (Shicong, 2022). HyProMag GmbH, a permanent magnet recycling company, has announced that it will build a permanent magnet production facility in Germany that uses recycled alloys. Nearly 60 percent of the facility's total cost will be funded by grants, suggesting that this ratio of grant funding is the upper bound for the unit economics of establishing a recycling plant to make financial sense for a private company (Mining Review Africa, 2022). This analysis will assume that a U.S.-based company would be willing to develop a similar recycling plant given that up to 60 percent of its upfront costs are covered by government investment. With the $100 million price tag of a recycling facility and 60 percent government investment, the DOD should invest a maximum of $60 million into a plant. At a minimum, it should invest $35 million, as this is how much it provided MP Materials to build a heavy rare earth separation facility (U.S. Department of Defense, 2022). This brings the estimated cost of this alternative to somewhere between **$35 million and $60 million.**

Effectiveness: Moderate

Recycling Investments scored **moderate** on effectiveness. Manufacturing with rare earth elements is a relatively new but up-and-coming field. As such, most of the rare earth elements in a given major end unit (wind turbines, electric vehicles, etc.) are newly mined and processed as opposed to recycled (Cammarata, 2022). This means that these major items will mostly be far away from reaching their end of life—the point where they could actually be recycled. For example, the life expectancy of a wind turbine is 20 to 25 years and that number is increasing (Jacobson, 2016). This alternative will likely be unable to produce recycled rare earth permanent magnets before a domestic manufacturing capacity is established. A rare earth processing plant takes approximately three to four years to build (Limitone, 2019). A $100 million recycling plant has can produce 3,000 tons of permanent magnets per annum (Shicong, 2022). This is output nearly 100 times more than the total magnets needed for the LRHW program as estimated in the effectiveness evaluation for Alternative I. This drives up the effectiveness rating for this alternative. This alternative would score higher on effectiveness if the impact would be realized sooner after the start of implementation.

Administrative Feasibility: High

Recycling Investments scored **high** on administrative feasibility. Under this alternative, the U.S. Department of Defense would award a contract to a private company to develop a rare earth recycling plant to support both commercial and defense purposes. This alternative's administrative feasibility is high because it requires little to no long-term implementation and follow-up. It also requires no inter-agency coordination. Additionally, the DOD has sufficient experience and infrastructure to build public-private partnerships like this and award contracts for projects with commercial and defense applications, including in the rare earth sector. In 2022, for example, the DOD awarded a $35 million contract for the design and construction of a facility "to process rare earth elements." This contract follows over $100 million that the DOD spent on similar rare earth supply chain resiliency investments in recent years (U.S. Department of Defense, 2022). Additionally, this alternative only needs to go through one department and does not require approvals from other agencies.

Political Feasibility: Moderate

Recycling Investments scored **moderate** on political feasibility. The Department of Defense has already authorized hundreds of millions of dollars for investments to improve rare earth supply chain resiliency, almost exclusively in the areas of mining, separation, and processing. This partially drives up the political feasibility score, as the government has taken steps to address closely related issues. These investments, however, did not include any funding for the recycling portion of the supply chain (U.S. Department of Defense, 2022). This alternative is likely unpopular amongst defense officials compared to other segments of the supply chain. Political feasibility would score higher if defense officials had publicly signaled a willingness to improve domestic rare earth recycling by taking concrete policy actions.

Alternative III: Establish a DIB Rare Earth Resiliency Advisory Board

The US Government regularly establishes advisory boards and committees with experts from academia and private industry to advise the government on policy areas of national importance. These groups can play a major role in shaping U.S. policy on a given topic (U.S. Department of Health and Human Services, 2018). The U.S. Department of Defense should establish an advisory board for issues related to rare earths, specifically those that are used in defense systems. The board should include industry leaders from across the private sector, think tanks, academia, and more. Such a board would address permanent magnet shortage and reliance issues by serving as a panel of experts that can formulate more targeted and nuanced recommendations specific to the defense industrial base.

The board should convene once per year before the National Defense Authorization Act process to advise the Department of Defense before submitting its funding requests to Congress. If the U.S. loses access to rare earth magnets and rare earths more generally, the government could call on this volunteer body of executives to the National Defense Executive Reserve through Title VII of the Defense Production Act (Cecire & Peters, 2020). The financial cost of this advisory board would be almost non-existent as it relies on industry executives who would be volunteering their time.

Evaluation: Advisory Board

Affordability: High

Advisory Board scores **high** on affordability. The primary cost of establishing a federal advisory committee through the Federal Advisory Committee Act is from staff salaries. In 2016, the federal government spent $371 million on over 1,000 federal advisory committees, bringing the average cost of each committee to $371,000 (Congressional Research Service, 2016). The Environmental Protection Agency (EPA) has established a handful of federal advisory committees. Some of them cost as much as $3 million per year, while others cost as little as $83,000 (Environmental Protection Agency, 2015). A federal advisory committee on rare earth supply chain resiliency will meet relatively infrequently. Therefore, it can be assumed that an REE supply chain resilience committee will have an annual cost somewhere between the EPA low of $83,000 and a federal average of $371,000. This cost is low compared to the projected costs of the other alternatives, explaining its high score. The estimated cost range of this alternative is **between $83,000 and $371,000.**

Effectiveness: Low

Advisory Board scores **low** on effectiveness. Establishing an Advisory Board does little to directly reduce the U.S. reliance on China for imports of high-strength rare earth permanent magnets. While the purpose of the board would be to combine industry and government expertise and propose more alternatives to improve supply chain resiliency, it does not do this in itself. This drives down its effectiveness rating. This alternative does, however, prepare the US Government for a possible event where China restricts rare earth and high-strength magnet exports. In an emergency like that, the defense community would have a pre-established board of experts who could effectively chart out the best response to Chinese export restrictions. These factors drive up the effectiveness rating.

Administrative Feasibility: Moderate

Advisory Board scores **moderate** on administrative feasibility. The federal government already operates thousands of advisory committees, with the DOD maintaining many of them (Congressional Research Service, 2016). The DOD has gained significant experience establishing and operating federal advisory committees. This drives the administrative feasibility rating up. Advisory committees involve a significant level of stakeholders within and outside of the government. The level of coordination required drives down this rating.

Political Feasibility: High

Advisory Board scores **moderate** on political feasibility. The federal government, including the DOD, operates over a thousand advisory boards already and continues to establish new ones to address policy issues of growing concern. A large portion of these advisory boards is established to address issues of mutual importance to both public and private interests (Congressional Research Service, 2016). Given that the issue of rare earth supply chain resiliency aligns with those factors, CASCOM and the DLA will likely face little resistance when pursuing this alternative. An advisory committee can be established only after senior officials within an agency review and approve it (U.S. General Services Administration, 2023). This means that only Defense Logistics Agency or CASCOM senior officials will need to approve an advisory board. This alternative would score higher on political feasibility if there was any public indication that the government would be open to this alternative or even any experts publicly advocating for it.

Outcomes Matrix & Recommendation

Criterion	Stockpile Increases	Recycling Investments	Advisory Board
Affordability	Moderate	Low	High
Effectiveness	High	Moderate	Low
Administrative Feasibility	High	High	Moderate
Political Feasibility	High	Moderate	Moderate
Total Score	**High**	**Moderate**	**Moderate**

Based on the evaluation of all policy alternatives against the defined criteria as illustrated in the matrix above, I recommend **increasing the strategic stockpiles of rare earth permanent magnets.** This alternative is the best balance between effectiveness, affordability, administrative feasibility, and political feasibility. Of all the criteria, this alternative scored lowest on affordability because of its somewhat high upfront costs. This alternative provides the added benefit of flexibility. In the future, once a domestic permanent magnet manufacturing industry is established, such a stockpile could be sold off in accordance with U.S. law to recoup some or all of the upfront costs.

Stockpile Increases scored moderate on affordability because of its estimated cost, which falls somewhere between $3.19 million and $4.25 million. It scored high on effectiveness because stockpiling has proven effective in ensuring access to critical materials and the Army could fully meet the demand of its hypersonic programs by stockpiling only an estimated 60,720 pounds of rare earth permanent magnets. It scored high on administrative feasibility because it requires almost no interagency coordination and the Defense Logistics Agency has significant experience in acquiring, transporting, and storing critical materials for the National Defense Stockpile. Lastly, Stockpile Increases scored high on political feasibility because the highest levels of government have made securing critical supply chains a top priority over the last two years and this alternative requires very few levels of approval. Overall, this alternative outperformed Recycling Investments and Advisory Board in every single criterion except for the Advisory Board Affordability. Of the three policy alternatives, Stockpile Increases has the best overall projected outcome.

Implementation

Stakeholder Roles & Perspectives

Defense Logistics Agency (DLA)

The Defense Logistics Agency is the principal and most relevant stakeholder for the successful implementation of this alternative. The DLA is responsible for the operation and oversight of the National Defense Stockpile, where the permanent magnets should be stored following procurement (Defense Logistics Agency, 2023). The DLA would be responsible for the logistical aspects of implementing this policy, including negotiation, acquisition, transportation, and storage of the permanent magnets. In 2021, the U.S. Department of Defense signed a $30 million contract with Lynas Rare Earths Ltd to establish a domestic processing capability of light rare earth elements. This, in addition to a wide range of other REE contracts, signaled the DOD's recognition of the importance of securing reliable access to rare earth components for defense purposes.

These actions have followed the guidance of Executive Order 13817, "the U.S. government's strategy to ensure secure and reliable supplies of critical minerals" (U.S. Department of Defense, 2021). The Defense Logistics Agency, a sub-agency of the Department of Defense, is therefore likely highly supportive of increasing strategic stockpiles of non-Chinese high-strength rare earth permanent magnets. The DLA works closely with the service branches and the defense industrial base to manage supply chains of critical materials. The U.S. Army Combined Arms Support Command should assume a facilitator role and utilize its close working relationship with the DLA to advocate for and implement this policy alternative.

DLA Strategic Materials is the sub-agency of the DLA responsible for the "analysis, planning, procurement and management of materials" for the National Defense Stockpile. Eric Mata is the Administrator of Strategic Materials and will be critical to the successful implementation of this alternative. Within Strategic Materials, the Directorate of Strategic Planning and Market Research will be responsible for advising the Administrator on the acquisitions strategy for permanent magnets. This directorate is also responsible for working with the military services on their critical material needs. CASCOM should coordinate with them to develop an acquisition strategy. Once the materials have been acquired, DLA Strategic Materials' Directorate of Material Management will be responsible for the logistical aspects of the implementation, including storage and maintenance (Defense Logistics Agency, 2023a).

Hypersonic Weapons Developers

Developers of hypersonic weapons are critical stakeholders in the implementation of this policy alternative. Some of the major defense contractors involved in hypersonic weapons development include Lockheed Martin, Northrop Grumman, and Raytheon (Judson, 2021). Permanent magnets are critical inputs in hypersonic weapons, therefore these contractors need guaranteed access to them.

While hypersonic weapons developers would not be directly involved in the logistical implementation of this alternative, the U.S. Army Combined Arms Support Command should work with these contractors to determine the number of permanent magnets that they would need to maintain the development of hypersonic systems in the event of a Chinese embargo. These contractors would very likely be highly supportive of this policy alternative considering how lucrative hypersonic development contracts are. Hypersonic weapons contracts are often worth billions of dollars (Young, 2023). These contractors would very likely have highly favorable opinions of any policy alternative that enables them to better complete these contracts without disruption.

Rare Earth Permanent Magnet Manufacturers

Manufacturers of rare earth permanent magnets are the final key stakeholder in the implementation of this policy. The Defense Logistics Agency would need to acquire permanent magnets from these manufacturers. After China, Germany and Japan are the two of the largest producers of high-strength rare earth permanent magnets. The manufacturers in these two countries would likely be very supportive of this policy alternative because it would spike demand, and therefore price and profits. However, these two countries combined account for less than 10 percent of global permanent magnet production as China produces over 90 percent of them (Yao, 2022). It is possible that Japanese and German manufacturers would not want or be able to fulfill such a large order at once, given their comparatively small share of the permanent magnet market. As of 2018, some of the leading German and Japanese manufacturers of sintered permanent magnets that the DLA could work with include TDK Corporation (Japan), Hitachi Metals Ltd. (Japan), Shin-Etsu Chemical Co., Ltd. (Japan), and VACUUMSCHMELZE GmbH & Co. (Germany) (Research and Markets, 2018).

Risks to Implementation

In recent years, policies that would strengthen and secure rare earth supply chains have been highly popular among all stakeholders. However, there are some minor risks to the successful implementation of this policy alternative. One potential risk is that non-Chinese manufacturers of permanent magnets would not be able to immediately fulfill such a large order that could sustain a stockpile through a Chinese embargo. Given their relatively small share of the global market, these manufacturers just might not have the capacity to fulfill the order at once. This risk is somewhat unlikely. More likely, however, is that the prices of magnets would increase, driving down the cost-effectiveness of this alternative.

Another possible risk to implementation is the lack of attention from government decision-makers. Over the last few years, many policies related to rare earth supply chains have been implemented. The issue is not receiving as much attention as it has over the last three years. Many initiatives to secure rare earth supply chains soon come to fruition, therefore, it may be more difficult to convince decision-makers of the need for this policy. This risk is unlikely because of the general sentiment in government and concern regarding a potential Chinese embargo.

One final risk to consider is underestimating the total amount of permanent magnets necessary to sustain a stockpile over multiple years. This risk is somewhat unlikely, as CASCOM and the DLA likely have more complete information on the technical specifications of hypersonic weapons and the exact permanent magnet needs.

To mitigate the risks to the implementation of this alternative, CASCOM should do the following:

1. Work with declassification authorities to increase the level of transparency on the specific permanent magnet needs without compromising security. This would allow the defense industrial base and other stakeholders to anticipate those needs and better prepare.

2. Stagger stockpile acquisitions over a multi-year period and across different permanent magnet manufacturers so that they will be able to better plan and more effectively fulfill the demand.

3. Overestimate the level of permanent magnets needed for a stockpile to ensure that there is no way an embargo would disrupt hypersonic weapons development. The Army's hypersonic program is relatively small compared to those of other branches. For example, the Navy plans to acquire over 3.5 times as many hypersonic weapons as the Army through its IR-CPS program. Surplus magnets could be used in other hypersonic programs (Congressional Budget Office, 2023). DLA Strategic Materials' Directorate of Material Management has the authorization to sell off surplus magnets (Defense Logistics Agency, 2023a). This could be done in the future to recoup the costs of overestimating demand.

The stakeholders most important to the successful implementation of this policy alternative are the Defense Logistics Agency, hypersonic weapons developers, and permanent magnet manufacturers. Three potential risks are that permanent magnet manufacturers would not be able to immediately fulfill such a large order, that government decision-makers would not give the issue the attention that it needs, and that CASCOM and the DLA underestimate the necessary amount of permanent magnets. To mitigate these risks, CASCOM should increase the level of transparency on magnet demand, stagger stockpile acquisitions over multiple years and across multiple suppliers, and overestimate the total need.

Conclusion

The lack of an end-to-end domestic rare earth magnet supply chain in the United States puts its hypersonic weapons programs at risk of disruption if U.S.-China tensions continue to escalate. Policy intervention is necessary to ensure that hypersonic supply chains are resilient and able to avoid disruption until production capacity is re-established at every phase of the permanent magnet supply chain.

Given that hypersonic weapons are the next frontier of advanced weapons, the defense sector needs to take steps to guarantee that research and development can continue with as few disruptions as possible. Adversaries of the United States, including Russia and China, have already and continue to make significant gains in hypersonic weapons development. Without policy intervention, the defense industrial base will experience significant disruptions in its hypersonic weapons supply chains if China were to impose export restrictions on rare earth permanent magnets.

To ensure that hypersonic weapons development can continue as planned, the Combined Arms Support Command needs to work with the Defense Logistics Agency to increase the stockpile levels of rare earth permanent magnets. This is an effective, feasible, and relatively affordable solution to ensure that hypersonic weapons developers have access to permanent magnets in the short term.

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Glossary

CASCOM	U.S. Army Combined Arms Support Command
DIB	Defense Industrial Base
DLA	Defense Logistics Agency
DOD	Department of Defense
DOE	Department of Energy
EPA	Environmental Protection Agency
HCM	Hypersonic cruise missile
HGV	Hypersonic glide vehicle
LRHW	Long-Range Hypersonic Weapon
NdFeB	Neodymium-iron-boron
NDS	National Defense Stockpile
ODNI	Office of the Director of National Intelligence
PM	[High-Strength Rare Earth] Permanent Magnet
REE	Rare earth element
REM	Rare earth metal
SmCo	Samarium-cobalt