

DEPENDING ON CHINA FOR RARE EARTH ELEMENTS: AN ACCEPTABLE
STRATEGIC VULNERABILITY FOR THE UNITED STATES?

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General Studies

by

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ABSTRACT

DEPENDING ON CHINA FOR RARE EARTH ELEMENTS: AN ACCEPTABLE STRATEGIC VULNERABILITY FOR THE UNITED STATES? by Major Jessica P. Klein, 133 pages.

This thesis addresses how U.S. reliance on China for critical rare earth elements leaves the United States exposed to a potential disruption of supply that constitutes a threat to national security. The study also reviews the history of U.S.-China trade relations and how China outflanked the United States in the global rare earths market. Rare earth elements are vital to electronic and national defense applications involving the Defense Industrial Base. Vulnerabilities in the U.S. rare earths supply chain are studied to discuss opportunities for domestic rare earth mining and separation independent of China. The study also reviews current mineral policies, acts, and measures to promote an adequate and reliable supply of critical materials for national security. The purpose of this thesis is to answer the primary research question: Can the United States ensure reliable resources of rare earth elements independent of China?

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ACRONYMS

CCP	Chinese Communist Party
CFIUS	Committee on Foreign Investment
CRS	Congressional Research Service
DIB	Defense Industrial Base
DFARS	Defense Federal Acquisition Regulation Supplement
DOC	Department of Commerce
DoD	Department of Defense
DOE	Department of Energy
DOI	Department of the Interior
DPA	Defense Production Act
EO	Executive Order
EU	European Union
FAST	Fixing America's Surface Transportation
FOA	Funding Opportunity Announcement
FY	Fiscal Year
GAO	Government Accountability Office
JOE	Joint Operating Environment
HPIP	High Priority Infrastructure Projects
HREE	Heavy Rare Earth Elements
IBAS	Industrial Base Analysis and Sustainment
INDPOL	Industrial Policy
LREE	Light Rare Earth Elements
NdFeB	Neodymium Iron Boron

NDS	National Defense Strategy
NTIB	National Technology and Industrial Base
PEA	Preliminary Economic Assessment
PFS	Preliminary Feasibility Study
PRC	People's Republic of China
R&D	Research and Development
REE	Rare Earth Elements
REO	Rare Earth Oxide
ROC	Republic of China
SEG	Samarium, Europium, Gadolinium
SmCo	Samarium Cobalt
SX	Solvent Extraction
U.S.	United States
USBM	U.S. Bureau of Mines
USFS	U.S. Forest Service
USGS	U.S. Geological Survey
USTR	U.S. Trade Representative
WTO	World Trade Organization

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CHAPTER 1

INTRODUCTION

Overview

The number one priority of the U.S. Department of Defense (DoD) is implementing the National Defense Strategy (NDS). The NDS states that we are now in an era of Great Power Competition, with our principal challengers being China, then Russia, and that we must move away from low-intensity conflict and prepare once again for high-intensity warfare . . . Under President Xi’s rule, the Chinese Communist Party (CCP) is heading even faster and further in the wrong direction – more internal repression, more predatory economic practices, more heavy-handedness, and most concerning for me, a more aggressive military posture . . . It is essential that we – as an international community – wake up to the challenges presented by China’s manipulation of the long-standing international, rules-based order that has benefited all of us for many decades . . . The U.S. NDS recognizes this critical challenge as we adapt and prepare our force to deal with China in this new era of Great Power Competition.¹

—Secretary of Defense Mark T. Esper, Munich Security Conference

This excerpt from a speech delivered at the Munich Security Conference clearly shows that U.S. policymakers currently consider the People’s Republic of China (PRC) to be the primary threat to U.S. national security. The U.S. is experiencing the contested norms of “increasingly powerful revisionist states” in which the government establishes “their own set of rules unfavorable to U.S. interest.”² The U.S. NDS focuses on the need

¹ Mark T. Esper, “As Prepared Remarks by Secretary of Defense Mark T. Esper at the Munich Security Conference,” U.S. Department of Defense, February 15, 2020, <https://www.defense.gov/Newsroom/Speeches/Speech/Article/2085577/remarks-by-secretary-of-defense-mark-t-esper-at-the-munich-security-conference/>.

² Director for Joint Force Development, U.S. Joint Chiefs of Staff (JCS), *Joint Operating Environment 2035: The Joint Force in a Contested and Disordered World*, U.S. Joint Chiefs of Staff, July 14, 2016, <https://apps.dtic.mil/docs/citations/AD1014117>, 4.

to “prepare our force to deal with China in this new era of Great Power Competition.”³

China’s “more aggressive military posture” is one reason the U.S. “must . . . prepare once again for high-intensity warfare.”⁴

Such preparations, however, face an inconvenient reality. “By 2035, the U.S. will confront a range of competitors seeking to achieve technological parity.”⁵ Production of technologically advanced weapons and equipment necessary to achieve victory in the high-intensity battles of the future requires rare earth elements (REEs). REEs are critical to many high-tech applications such as computer laptops and cell phones; green technologies, such as solar and wind power; and defense technologies, such as missile guidance systems, lasers, radars, and sonars. However, while the U.S. was once self-sufficient in mining and producing REEs, today it relies on China for 80 percent of its supply.⁶ Reliance on a strategic adversary for natural resources that are essential to producing advanced weaponry is not prudent.

The U.S. government has recognized this problem and is working to end the dependency on China for REEs. The Joint Operating Environment (JOE) also addresses how contested norms and persistent disorder will manifest in the future security

³ Esper, “As Prepared Remarks by Secretary of Defense Mark T. Esper at the Munich Security Conference.”

⁴ Ibid.

⁵ JCS, *Joint Operating Environment 2035*, 15.

⁶ U.S. Library of Congress, Congressional Research Service (CRS), CRS Report R45810, *Critical Minerals and U.S. Public Policy*, by Marc Humphries (Washington, DC: Office of Congressional Information and Publishing, June 28, 2019), 31.

environment.⁷ The JOE details the trends and implications of new science, technology, and engineering made available by 2035 and the integral nature of these systems in battlefield success. Therefore, a steady and secure supply line of REEs must be available to ensure the development of new weapons systems through research and development (R&D). China has already demonstrated its willingness to use REEs as an economic and political weapon in the past as will be demonstrated below. It could easily do so again in the future with the U.S. as the target. The strategic vulnerability created by U.S. reliance on the PRC for REEs undermines national security. Mitigations presented will explore possible ways to break free from China as the main source of supply for REE. The increasing tension in the U.S. - PRC relationship adds to the urgency of pursuing this goal of eliminating U.S. dependency. This thesis examines the challenges involved with the current REE supply chain and explores the possibility of independence from China by 2035 in line with the JOE, when Defense Secretary Esper predicts U.S. competitors will reach technological parity.

Historical Roots of U.S. -China Tensions

There are many causes for the tension between the U.S. and China; disputes over human rights, the protection of intellectual property, access to markets, and many other matters. No area of contention, however, is a greater source of tension than the disagreement between the U.S. and the PRC over the present and future status of Taiwan. According to the Department of State, the U.S. does not support Taiwan's independence

⁷ JCS, *Joint Operating Environment 2035*, 4.

from China, but the U.S. does maintain an unofficial relationship with Taiwan as a part of U.S. goals.⁸ The PRC asserts that Taiwan is a PRC province and that all U.S. interaction with Taiwan, especially in regard to U.S. arms sales to Taiwan, represent provocative violations of Chinese sovereignty. The PRC refuses to renounce the use of military force to gain control of Taiwan. Since 1979, when the Taiwan Relations Act (TRA) was passed by Congress and signed into law by President Jimmy Carter, the U.S. has been bound to “make available to Taiwan such defensive articles and defense services in such quantity as may be necessary to enable Taiwan to maintain a sufficient self-defense capability.”⁹ The Taiwan Relations Act also enjoins the U.S. military to “maintain the capacity to resist any use of force or other forms of coercion that would jeopardize the security, or the social or economic system, of the people of Taiwan.”¹⁰ These conflicting positions regarding Taiwan seem to have the PRC and the U.S. on a collision course. The possibility that the U.S. might become involved in a high-tech war with China over Taiwan, a war that certainly would mean an end to all REE exports from China to the U.S., makes it necessary to end REE dependency as soon as possible.

The U.S.-PRC dispute over Taiwan began in 1950. During the Second World War, the U.S. had been a military ally of the Republic of China (ROC), which was

⁸ U.S. Department of State (DOS), Bureau of East Asian and Pacific Affairs, “U.S. Relations with Taiwan,” Bilateral Relations Fact Sheet, U.S. Department of State, August 31, 2018, <https://www.state.gov/u-s-relations-with-taiwan/>.

⁹ Taiwan Relations Act of 1979, Public Law 96-8, U.S. Code 22 (1979), §§ 3301 et seq.

¹⁰ Ibid.

dominated by the Nationalist Party led by Chiang Kai-shek. After the war ended, the U.S. tried to mediate some form of accommodation between Chiang's ROC government and Mao Zedong's CCP insurgents who had been trying to overthrow the ROC government and seize control of China since 1927. This mediation effort failed, and after three years of civil war, CCP forces overran mainland China. On October 1, 1949, with almost all of mainland China under CCP control, Mao Zedong proclaimed the establishment of the PRC. In December, Chiang Kai-shek ordered what remained of his ROC government to abandon their last position on the Chinese mainland and flee to Taiwan. At that time, the U.S. assumed that CCP forces would soon mount a successful attack on Taiwan and the Chinese civil war would be over.

This assessment led President Truman to declare a hands-off approach to Taiwan. On January 5, 1950, he issued a policy statement that made his position clear. The U.S. had no secret plans regarding Taiwan and no intention of trying to obtain any rights or privileges on Taiwan. The U.S. would not provide military aid or advice to Chinese forces on Taiwan and the U.S. military forces would not interfere in the existing situation. A key sentence read, "The U.S. Government will not pursue a course which will lead to involvement in the civil conflict in China."¹¹

This policy was discarded after North Korea invaded South Korea on June 25, 1950. Two days later, on June 27, President Truman dispatched the Seventh Fleet to patrol the Taiwan Strait and block any PRC attempt to attack Taiwan. On July 28, the

¹¹ Immanuel C.Y. Hsu, *The Rise of Modern China* (New York: Oxford University Press, 1970), 785.

U.S. sent a chargé d'affaires to Taipei, and three days later, General MacArthur flew to Taipei from Tokyo to visit Chiang Kai-shek. On August 4, 1950, General MacArthur's deputy chief of staff arrived in Taipei to establish channels for regular liaison between MacArthur's Far East Command and the Nationalist military.

These actions that saved Chiang Kai-shek's Nationalist government from likely total destruction and preserved Taiwan's independence from the PRC clearly placed the U.S. square in the middle of the Chinese civil war. Subsequent U.S. actions, such as sending a Military Assistance Advisory Group to Taiwan in April 1951, raising the status of the U.S. diplomatic representative to Taiwan to the ambassadorial level, and signing a mutual defense pact with Taiwan in 1954 increased U.S. support for the CCP's avowed mortal enemies, Chiang Kai-shek and his Nationalist Party. The PRC was steadily increasing resentment and anger toward the U.S.

The U.S. relations with the PRC continued to be extremely hostile during the 1960s. The PRC sent military personnel and large amounts of weapons and supplies to help North Vietnam fight American forces during the Vietnam War. The U.S. maintained diplomatic relations with the ROC government, refused to establish diplomatic relations with the PRC, and continued to block PRC admission into the United Nations. There were, however, those in the U.S. and the PRC who were beginning to feel that this antagonistic, openly adversarial relationship needed to change. Chinese leaders were beginning to feel that the Soviet Union was a greater short-term threat to China than the U.S. The result was a developing openness to U.S. overtures for change. In the U.S. important political figures were thinking about the benefits of ending efforts to isolate the PRC. For example, in an article published in October 1967 in *Foreign Affairs*, former

Vice President Richard Nixon stated, “The world cannot be safe until China changes. Thus, our aim, to the extent that we can influence events, should be to induce that change.”¹²

Richard Nixon was elected to the presidency in 1968 and, even as the Vietnam War was still raging, began pursuing the goal of improving relations with China. In April 1971, he lifted the U.S. embargo, which former President Harry S. Truman had imposed in response to China’s intervention in the Korean War, against China. He also took steps that made travel between the U.S. and China easier. Nixon pushed to strengthen relations, trade, and travel between the two countries. In February 1972, he even traveled to China to meet with Mao Zedong in Beijing. Even with the embargo lifted, the volume of trade between the U.S. and the PRC only had a value of U.S. \$4.7 million due to years of mutual hostility.¹³

Following the Nixon Administration and President Ford’s brief presidency, President Jimmy Carter, who assumed office on January 20, 1977, took truly significant steps to improve U.S.-China relations. On December 15, 1978, he announced that the U.S. would break diplomatic relations on January 1, 1979, with the Nationalist ROC government in Taiwan and at the same time establish diplomatic relations with the PRC. Carter also established programs to assist PRC development and promoted a major trade

¹² Richard M. Nixon, “Asia After Viet Nam,” *Foreign Affairs*, October 1967, <https://www.foreignaffairs.com/articles/asia/1967-10-01/asia-after-viet-nam>.

¹³ Jeffrey L. Lee and JeNelle Matheson, “Five Years of US-China Trade,” *The China Business Review* 11, no. 2 (March 1984), <https://lumen.cgsccarl.com/login?url=https://search-proquest-com.lumen.cgsccarl.com/docview/202678233?accountid=28992>.

accord between the nations that was signed in May. The remarks made by the U.S. Secretary of Commerce, Juanita Krebs, upon signing the agreement in Canton, China, reflect the optimistic perspective that dominated U.S. policy toward China then and for years to follow:

For 30 years, the people of the U.S. had little or no commercial or other contacts with nearly one-quarter of the population of the world. Today, we take a major step together in resuming the unimpaired exchange of goods and services—and, therefore, the exchange of ideas, experiences, and goodwill.¹⁴

Trade between the U.S. and China grew rapidly during the Carter Administration. In 1978, bilateral trade was estimated at U.S. \$1.8 billion; by 1980 it had jumped to U.S. \$4.8 billion.¹⁵ Presidents who succeeded the Carter Administration continued Carter's policies of encouraging trade with China, even as China adopted mercantilist policies and currency manipulation to encourage American manufacturers to move jobs and supply chains to China.¹⁶ For years, while the U.S. trade deficit with China was ballooning, American presidents continued to promote the idea that more trade with China was good. A high level of integration between the two economies was viewed as a way to reduce Chinese incentives to challenge U.S. national security interests. Increased foreign trade was supposed to stimulate economic reform in China. Trade with Western nations would

¹⁴ Leonard Silk, "U.S.-China Trade Pact Is Initialed," *The New York Times*, May 15, 1979, <https://www.nytimes.com/1979/05/15/archives/uschina-trade-pact-is-initialed-strain-evident-but-mrs-krebs.html>.

¹⁵ Lee and Matheson, "Five Years of US-China Trade," 18.

¹⁶ Kurt M. Campbell and Ely Ratner, "The China Reckoning: How Beijing Defied American Expectations," *Foreign Affairs* (March/April 2018): 60-70, <https://www.foreignaffairs.com/articles/china/2018-02-13/china-reckoning>.

bring in Western ideas and create popular demands for more personal freedoms and a healthier civil society, so the thinking went. As former President George H. W. Bush proclaimed, “No nation on earth has discovered a way to import the world’s goods and services while stopping foreign ideas at the border.”¹⁷

The U.S. hoped the increased trade interaction with China would naturally lead to an adoption of Western political and economic principles. However, this did not come to pass. Chinese Premier Deng Xiaoping’s economic reform of 1978 took advantage of “four hundred million liberated ‘peasants’ from their rural livelihoods for ‘cheap labor’.”¹⁸ The lowered labor costs attracted foreign direct investment, whilst businesses remained state-owned. China managed to adopt capitalist values without democratic reforms.

Current U.S.-China Tensions

With increased economic power, the CCP uses coercion to “shape the behavior of their regional neighbors.”¹⁹ The country uses pervasive propaganda and political indoctrination, ubiquitous surveillance, harsh punishment of dissidents, control of internet

¹⁷ Campbell and Ely Ratner, “The China Reckoning: How Beijing Defied American Expectations,” 60-70.

¹⁸ Deng Xiaoping assumed leadership after Mao Zedong’s death in 1976. Deng Xiaping is regarded as the father of reforms in China. He propelled China out of a centrally planned economy and into the global market. See Julie Michelle Klinger, *Rare Earth Frontiers: From Terrestrial Subsoils to Lunar Landscapes* (Ithaca: Cornell University Press, 2017), 108.

¹⁹ JCS, *Joint Operating Environment 2035*, 6.

content and access, and the falsification of history and current reality. President Bush and many other U.S. political leaders thought such acts could not be done. CCP leaders created a totalitarian state that has engaged with the world, absorbed wealth and technological knowledge from the world, became “the factory of the world,” and the leading supplier of many products and natural resources.²⁰ Now China stands ready, confident in their power to compete for world domination.

Beijing’s new aggressiveness and belligerence was a shocking wake-up call to U.S. policymakers. Articles like the one titled “China Reckoning: How Beijing Defied American Expectations” written by Kurt M. Campbell, U.S. Assistant Secretary of State for East Asian and Pacific Affairs from 2009 to 2013, and Ely Ratner, Deputy National Security Advisor to former Vice President Joe Biden, explain how and why U.S. policymakers totally misjudged their ability to influence CCP decision-makers.²¹ These two former high-ranking officials conclude that U.S. leaders need to abandon what they call “hopeful thinking” that characterized the U.S. approach to China since President Nixon and Henry Kissinger began their schemes to engage China. They note that U.S. leaders need to “base policy on a more realistic set of assumptions about China” because

²⁰ White House Office of Trade and Manufacturing Policy, *How China’s Economic Aggression Threatens the Technologies and Intellectual Property of the United States and the World* (Washington, DC: The White House, June 2018), 1.

²¹ Campbell and Ratner, “The China Reckoning: How Beijing Defied American Expectations,” 60-70.

in China, “Washington now faces its most dynamic and formidable competitor in modern history.”²²

Much of the great economic power that makes it possible for China to compete with the U.S. for leadership around the world came from the transfer of wealth, manufacturing capacity, intellectual property, resource extraction and processing capability, and other attributes of national power from the U.S. to China. What happened to REE mining, processing, and manufacturing in the U.S. is only one example of how China worked to create a situation that allowed it to become the dominant player in an essential part of the world economy. The COVID-19 pandemic, which began sweeping across the globe in the spring of 2020, has revealed other areas in which China manipulated the international trading system and established a monopolistic position.

The message is clear: U.S. policymakers cannot rely on “hope” as a strategy when dealing with China. This message lies at the heart of Secretary of Defense Esper’s remarks at the Munich Security Conference. He states that the international community must “wake up” to the reality of what China is doing.²³ He points out that the CCP is taking China faster and further down a path of intensifying internal repression and increasing external confrontation with the U.S. and other countries.²⁴ Some areas of confrontation, such as China’s border dispute with India or its dispute with Vietnam over

²² Campbell and Ratner, “The China Reckoning: How Beijing Defied American Expectations,” 60-70.

²³ Ibid.

²⁴ Ibid.

oil exploration rights in the South China Sea, do not immediately involve the U.S. Others, however, do involve the U.S. For example, the PRC claims that Japan's Senkaku Islands (known as Diaoyu in China) are sacred Chinese territory. Meanwhile, the U.S. considers the islands to be Japanese for purposes of the U.S.-Japan Defense Treaty.²⁵ Similarly, the PRC claims that Taiwan is only a renegade province of the PRC and that U.S. ties to Taiwan represent an unacceptable interference in China's internal affairs. This represents a direct challenge to U.S. policy regarding Taiwan and the TRA.²⁶

This question has become increasingly contentious because of the political and social changes that have occurred in Taiwan during the last three decades. When Chiang Kai-shek fled to Taiwan in 1949 with his ROC government, he dreamed of building an army to retake China. He imposed martial law on the island, preventing any political opposition to the Nationalist Party. The Chinese civil war was still being fought as far as Chiang and the ROC government were concerned. The official government position was that Taiwan was part of China and that unification would occur at some time in the future after the CCP had either disappeared or reformed. Then in 1987, twelve years after Chiang Kai-shek's death, martial law was lifted, opposition parties began forming, and Taiwan began the march to becoming the vibrant multi-party democracy it is today. Most significantly, the political party that enjoys the most popular support and now leads the

²⁵ Ankit Panda, "Mattis: Senkakus Covered Under US-Japan Security Treaty," *The Diplomat*, February 6, 2017, <https://thediplomat.com/2017/02/mattis-senkakus-covered-under-us-japan-security-treaty/>.

²⁶ The Taiwan Relations Act became public law on April 10, 1979 and signed by President Carter to formally recognize the PRC.

Taiwan government has no interest in unifying with the PRC. This is the result of a growing consciousness in which Taiwan residents self-identify as Taiwanese, not Chinese.

The CCP is distressed by these changes in Taiwan because it means that time is not on their side. Unable to win the hearts and minds of the Taiwanese people, the PRC has turned to threats and provocative military maneuvers in an attempt to frighten them into submission. PRC bombers regularly fly up and down the Taiwan Strait and have begun to fly around the island in a show of force. PRC fighter aircraft have been sent across the midpoint of the Taiwan Strait to probe Taiwan's defenses. The U.S. has responded by flying B-52s along Taiwan's east coast and sending naval vessels through the Taiwan Strait.²⁷ The arms sales to Taiwan mandated by the Taiwan Relations Act also continue. As PRC frustrations over developments on Taiwan and U.S. support for Taiwan intensifies, this is not the time for the U.S. to be dependent on the PRC for REEs.

History of the Rare Earths Industry: China and the U.S.

China was not always the leading producer of rare earths of the world. In the 1960s, the U.S. was the world leader and producer of REEs. China had begun to produce REEs on a small scale for lighter flints and thorium gas nitrate for mantles.²⁸ However,

²⁷ Caitlin Doornbos, "U.S. sends three aircraft near Taiwan Strait after back-to-back Chinese drills near Taiwan," *Stars and Stripes*, February 12, 2020, <https://www.stripes.com/news/pacific/us-sends-three-aircraft-near-taiwan-strait-after-back-to-back-chinese-drills-near-taiwan-1.618432>.

²⁸ Minggin Wang and Xuehong Dou, "The History of China's Rare Earth Industry," In *Episodes from the History of the Rare Earth Elements*, ed. C. H. Evans

70 percent of the annual global production of REEs originated from the Mountain Pass mine in Southern California, which was owned and operated by the American company Molycorp.²⁹ At this location, europium was mined for red phosphors used in television screens. Molycorp had its own refinery, which made supply chains transparent and less complicated. Manufacturing companies like Magnequench, an American high-tech subsidiary company of General Motors and producer of neodymium magnets, relied heavily on Molycorp's materials.³⁰

During this time, China was a developing country recovering from the after-effects of the Great Leap Forward.³¹ Although rare earth deposits were abundant in China, the country mined limited quantities of REEs. It was not until Xu Guangxian, a chemist and the father of China's rare earth industry, applied his knowledge of isolating isotopes to REEs in 1975 that China began to exploit this resource for economic gain. Xu was able to industrialize his methods at the mine in Baotou, China. As the world's

(Netherlands: Kluwer Academic Publishers, 1996), 134, https://doi.org/10.1007/978-94-009-0287-9_8.

²⁹ Klinger, *Rare Earth Frontiers*, 82.

³⁰ John J. Tkacik, Jr., "Magnequench: CFIUS and China's Thirst for U.S. Defense Technology," The Heritage Foundation, Washington, DC, May 2008, 1-2.

³¹ The Great Leap Forward refers to Mao Zedong's attempt to rapidly industrialize China's peasant economy, but it failed, and 10-40 million people died between 1959-1961. See Virginia Harrison and Daniele Palumbo, "China anniversary: How the country became the world's 'economic miracle'," *BBC*, October 1, 2019, <https://www.bbc.com/news/business-49806247>.

reliance on REEs grew, China's production rates increased by 40 percent from 1978 to 1989.³²

According to Dr. Julie Klinger, author of *Rare Earth Frontiers*, two key events also propelled China's success in the rare earth industry: Deng Xiaoping's economic reforms of 1978 and the Thatcher- Reagan deregulation of capital.³³ The U.S.' neoliberal movement and strict environmental policies hindered domestic REE exploration, mining, and production, allowing time for China to out produce America. With lower labor costs in China, the U.S. companies started to subcontract parts of their refinement process to Chinese companies, slowly losing their clear supply lines.

During Deng Xiaoping's economic reform period, China took steps to close the large gap in technology with the U.S. In 1986, four Chinese scientists proposed to address this gap through the National High-Tech R&D Program, also known as Program 863.³⁴ The program provided a strategic vision for China to develop its technological capabilities and become competitive with international industries. This pushed China to dive deeper into the rare earths industry. As the U.S. interest in rare earths waned, China's investment and interests in REEs took an upturn. The government encouraged Chinese rare earth companies to affiliate with foreign companies in the high-tech arena

³² Wang and Dou, "The History of China's Rare Earth Industry," 134.

³³ Klinger, *Rare Earth Frontiers*, 105-108.

³⁴ Ministry of Science and Technology of the People's Republic of China, "National High-tech R&D Program (863 Program)," accessed April 13, 2020, http://www.most.gov.cn/eng/eng/programmes1/200610/t20061009_36225.htm.

through joint ventures and partnerships. By working closely with their foreign partners, the Chinese learned advanced technological methods either through “unintentional osmosis or through intentional diversion.”³⁵

One company that lost most of their cutting-edge technology and processes to China was Magnequench. In the 1980s, the company supplied 85 percent of the world market share of neodymium magnets, used in servo motors of precision guided munitions.³⁶ The company was also known for the development of smart bombs like joint direct attack munitions. Magnequench’s sole REE provider was Molycorp, which had multiple production setbacks due to the strict environmental standards in the U.S.

With a dwindling domestic supply stream, Magnequench sold a majority of their shares to two Chinese state-owned companies called San Huan New Material and Chinese National Nonferrous Metals Import in 1995. The chairman of San Huan, Zhang Hong, son-in-law of former Chinese Premier Deng Xiaoping, stepped in as chairman of Magnequench. The other Chinese investor, Chinese National Nonferrous Metals Import, was also run by a son-in-law of Deng Xiaoping. It was clear the companies wanted to acquire pioneering technologies for military applications, including “exotic materials.”³⁷

³⁵ Office of the U.S. Trade Representative, Executive Office of the President, *Findings of the Investigation into China’s Acts, Policies, and Practices related to Technology Transfers, Intellectual Property, and Innovation Under Section 301 of the Trade Act of 1974* (Washington, DC: The White House, March 22, 2018), 28.

³⁶ MP Materials, “What are Rare Earth Elements?” accessed April 14, 2020, <https://mpmaterials.com/products>.

³⁷ Tkacik, “Magnequench,” 3.

As America's first line of defense of U.S. companies and technologies from potential foreign acquisitions in support of national security, the Committee on Foreign Investment in the U.S. (CFIUS) attempted to mediate the sale.³⁸ Eventually, CFIUS reached an agreement with the Chinese companies that would require Magnequench's production to remain in Indiana for ten years.³⁹ However, the Chinese firms, who owned a 62 percent majority of the company, duplicated Magnequench's neodymium iron boron (NdFeB) magnet production line in China and ceased operations in Indiana, leaving many American employees jobless.⁴⁰ NdFeB is the strongest magnet ever created with many defense applications (Chapter Two discusses NdFeB permanent magnets further).

Appalled at the situation, U.S. Senator James Inhofe (R-OK) stated:

Over 12 years, [Magnequench] has . . . moved piecemeal to China, leaving the U.S. with no domestic supplier of neodymium, a critical component of rare earth magnet. The blame rested with the CFIUS because CFIUS approved this transfer in 1995 and failed to enforce the terms of its approval.⁴¹

³⁸ The loss of Magnequench to a Chinese- joint venture meant the loss of U.S. patents and intellectual rights manufacturing permanent magnets. Magnequench was able to merge with a Canadian rare-earths firm, AMR in 2005, and changed its name to Neo Material Technologies in 2006. Neo Material Technologies was acquired by Molycorp in 2012. After Molycorp's bankruptcy in 2015, Neo Performance Materials emerged as a new private company with a metal processing facility in Estonia.

³⁹ Tkacik, "Magnequench," 3.

⁴⁰ Scott L. Wheeler, "Missile Technology Sent to China," *Insight Magazine* (February 3, 2003).

⁴¹ CFIUS, part of the Secretary of Treasury, is the organization that seeks balance between America's open investment policy and national security under the Foreign Investment and National Security Act of 2007.

The “Mountain Pass Era” was coming to a close by 1995 and marked the beginning of the “Chinese Era” in the rare earths industry.⁴² During this year, Congress voted to close the U.S. Bureau of Mines (USBM). This bureau was an especially important part of the Department of the Interior (DOI) that focused not only on the safety and health of mine workers, but also filled a gap the government needs now. The bureau used to collect, analyze, and disseminate mining and processing methods for over 100 minerals. Even with a limited budget, the USBM was the recipient of 35 awards from *Research and Development Magazine*, competing against major companies and organizations like Hitachi, DuPont, the Department of Energy (DOE), and the National Aeronautics and Space Association.⁴³ Using cutting edge technology, the bureau was able to find non-intrusive ways to recover minerals without disturbing the surface land and even found a way to use bacteria to remove arsenic and cyanide from wastewater.⁴⁴ During the Cold War, the bureau also developed techniques to recover strategic minerals, such as cobalt, to reduce U.S. vulnerability to import blockages in international crises. The loss of USBM marked the decline of American mining innovation and expertise.

After 1995, Mountain Pass, a rare earth provider for Magnequench, struggled to remain operational. Constantine Karayannopoulos, former chairman of Molycorp, stated:

⁴² U.S. Geological Survey (USGS), “Rare Earth Elements—Critical Resources for High Technology,” by Gordon B. Haxel, James B. Hedrick, and Greta J. Orris, Fact Sheet 087-02, 2002, <https://pubs.usgs.gov/fs/2002/fs087-02/>.

⁴³ U.S. Department of the Interior (DOI), “U.S. Bureau of Mines,” in *Annual Report FY 1995* (Washington, DC: U.S. Department of the Interior, 1996), 49-51.

⁴⁴ Ibid.

getting the rare earths out of that rock is nasty business requiring toxic acids and lots of water. In fact, the mine was shut down by the state of California in 1998 after radioactive water seeped into the surrounding Mojave Desert from an underground pipe. The mine lay dormant for a decade, giving China an opportunity.⁴⁵

Halting the only producer of domestic rare earths powders removed 20 percent of the world's supply from the market, severely impacting downstream companies.

With the U.S. government staying out of private businesses, China successfully outflanked the U.S. with reduced labor cost and higher manufacturing capability. China's relaxed environmental restrictions also contributed to their success in the rare earths market. By 2000, virtually all separated Rare Earth Oxide (REOs) imported into the U.S. came from China.

Since then, China has had difficulty balancing global demand, domestic consumption, and managing the harmful environmental effects of producing REEs. Refining just one ton of REO can produce 63,000 m³ of waste gas containing sulfur acid and hydrofluoric acid, 200 m³ of acid-containing sewage water and 1.4 tons of radioactive industrial waste.⁴⁶ In an effort to resolve these issues, China tried to restructure the rare earth industry.

⁴⁵ Constantine Karayannopoulos, "Modern life's devices under China's grip?" interview by Lesley Stahl, *60 Minutes*, March 22, 2015. <https://www.cbsnews.com/news/rare-earth-elements-china-monopoly-60-minutes-lesley-stahl/>.

⁴⁶ Jiabao Li and Jie Liu, "Rare earth Industry adjusts to Slow Market," *China Daily*, September 7, 2009, http://www.chinadaily.com.cn/bw/2009-09/07/content_8660849.htm.

Beginning in 2009, China restricted REE export quotas, adversely affecting the price and quantity of REE in the global markets. Simultaneously, China's domestic supply improved and REE prices decreased by 36 percent.⁴⁷ Consequently, many companies brought their operations to China to access abundant REE supply streams. A U.S. Trade Representative (USTR) official said in 2011 that the USTR continues to be "deeply troubled" by China's use of "market-distorting export restrictions" on REEs.⁴⁸ A Congressional Research Service (CRS) report stated that

Many analysts contend that China's recent actions to consolidate its rare earth production and restrict exports are intended to promote the development of domestic downstream industries . . . by ensuring their access to adequate and low-cost supplies of rare earths. It is further argued that China's rare earth export policies are intended to induce foreign rare earth users to move their operations to China, and subsequently, to transfer technology to Chinese firms. China denies that its rare earth policies are political, discriminatory, or protectionist, but rather, are intended to address environmental concerns in China and to better manage and conserve limited resources.⁴⁹

There is undoubtedly environmental issues China has to resolve regarding REEs.

However, China's monopoly over the rare earths industry and continuing economic

⁴⁷ Justine Underhill, "Inside Look at the Rare Earth Industries," video, *The Real Vision*, 21:01, February 27, 2019, <https://player.vimeo.com/video/320806555>.

⁴⁸ Michael Martina and Ruby Lian, "China's latest rare earth move disappoints EU, U.S.," *Reuters*, July 14, 2011, <https://www.reuters.com/article/us-china-rareearth-chen-idUSTRE76D1XB20110714>.

⁴⁹ U.S. Library of Congress, Congressional Research Service (CRS), CRS Report R42510, *China's Rare Earth Industry and Export Regime: Economic and Trade Implications for the United States*, by Wayne M. Morrison and Rachel Tang (Washington, DC: Office of Congressional Information and Publishing, April 30, 2012), 2.

aggression through regulatory schemes to compel technology transfers from foreign companies and state-backed technology seeking Chinese investments is troublesome.⁵⁰

Also, the 2010 dispute between China and Japan that came to involve China's use of REEs as a weapon of choice in economic aggression against Japan stands as a warning of possible Chinese actions. In 2010, the world took action against Chinese economic aggression. The Obama Administration filed a complaint alongside the European Union (EU) and Japan to the WTO to force China to loosen restrictions on REE exports on March 13, 2012. Vice Premier Liu of the PRC responded that he believes China's "measures comply with WTO rules" and describes the accusation of China using its position to control a valuable commodity to benefit Chinese firms as "groundless."⁵¹ The WTO ruled against China and the country resumed its exportation of REEs. In a statement by EU Trade Commissioner Karel De Gucht, "No one country can hoard its raw materials from the global marketplace at the expense of its other WTO partners." After recommencement of REE exportation, the U.S. became the object of criticism for bringing down the price of rare earths, making opening new REE mines harder.⁵²

⁵⁰ White House Office of Trade and Manufacturing Policy, "How China's Economic Aggression Threatens the Technologies and Intellectual Property of the United States and the World," 2.

⁵¹ William Wan, Keith B. Richburg and David Nakamura, "U.S. to Challenge China's Curbs on Mineral Exports; China Says it will Push Back," *The Washington Post*, March 13, 2012, https://www.washingtonpost.com/world/national-security/us-to-challenge-chinas-curbs-on-mineral-exports/2012/03/12/gIQAV8BX8R_story.html.

⁵² Julie Michelle Klinger, interview by Justine Underhill. "Inside Look at the Rare Earth Industries."

The REE Challenge

As this brief historical overview of various developments in U.S.-PRC relations shows, for years, U.S. policymakers were optimistic about how that relationship would develop. This optimism led the U.S. to grant China the most-favored-nation status in U.S. markets, support China's entry into the World Trade Organization (WTO), and encourage U.S. investment in China. U.S. leaders hoped that the result would be a China satisfied to operate within what Secretary Esper calls "the long-standing international, rules-based order."⁵³ Instead, China manipulated this rules-based order to its advantage. As a result, the PRC now dominates many global supply chains, including the REE supply chain, in ways that threaten U. S. national security, including the REE supply chain. Once self-sufficient in domestically produced REEs, over the past 20 years, the U.S. has become 100 percent reliant on rare earth imports, primarily from China.

The U.S. reliance on Chinese imports to satisfy REE requirements is an especially significant strategic vulnerability because REEs are vital to the U.S. defense industrial complex. They are needed to build the high-tech weapons and equipment needed to fight the high-intensity wars that Secretary Esper says we must be prepared to fight. For example, rare earth magnets provide the counterbalance needed to make defense equipment lighter and more compact when space and weight are constraints. Any disturbance within the already complex REE supply chain could have severe consequences on the production of U.S. defense equipment. The absence of REEs would

⁵³ Esper, "As Prepared Remarks by Secretary of Defense Mark T. Esper at the Munich Security Conference."

decrease innovation for new equipment in line with the Army's modernization plan. Given the Army's new focus on modernization and the creation of the Combat Capabilities Development Command, part of the Army Futures Command, a halt on Chinese exports of REEs would severely impact U.S. capability to maintain, develop, and improve U.S. defense weapons.

Ending reliance on Chinese REEs must occur because China has already shown a willingness to use REEs as a political and economic weapon to achieve certain objectives. On September 7, 2010, a Chinese fishing boat hit two Japanese Coast Guard vessels near the highly disputed territory of the Senkaku Islands. The Japanese Coast Guard seized the boat and pulled it into port. The Chinese government quickly condemned the seizure and demanded the immediate release of the trawler and the crew. Japan released the trawler and the crew on September 13 but continued to hold the captain. On September 21, the Chinese Prime Minister, the Chinese Prime Minister Wen Jiabao, while attending a meeting of the United Nations General Assembly in New York City, stated that Japan would face the most severe consequences if the captain were not released.⁵⁴ That same day, China ordered customs officials to block the export of REEs to Japan. Executives in foreign REE industry companies were also instructed to stop exporting to Japan. They were further told that the export ban might be extended if the captain was still in Japanese custody by the end of September. On September 24, the captain was released to Chinese officials and returned to China, ending the crisis. The

⁵⁴ CNN Wire Staff, "Chinese premier wants immediate, unconditional release of boat captain," *CNN*, September 21, 2010, <https://www.cnn.com/2010/WORLD/asiapcf/09/21/japan.china.fishing.captain/index.html>.

PRC government subsequently denied that it had implemented an embargo on REE exports to Japan, but Japan and the world felt differently.

Other Chinese actions have raised awareness of the dangers inherent in relying on China for REEs. The country at times has claimed that it was limiting exports of REEs as part of a program to crack down on smuggling. It has also stated that it is limiting exports to curtail pollution and preserve resources in the national interest. These may be laudable objectives, but they still serve to illustrate the need to break free from a reliance on China for these essential minerals.

This study will examine the problems and potential dangers for the U.S. defense supply chain that could arise because the U.S. relies solely on foreign imports for REEs. It also looks at viable upstream and midstream mining and separation plants in North America and Australia to secure reliable supply chains for the U.S. defense industry. Solutions offered will assist in achieving the goals of the Army Modernization Strategy and supporting the NDS.

Primary Research Question

The purpose of this thesis is to answer the following question: Can the U.S. ensure reliable resources of REEs independent of China?

Secondary Research Questions

To answer the primary research question, the following secondary questions must be explored:

1. Why are REEs critical to the U.S. economy and the U.S. military?
2. What are the vulnerabilities in the REE supply chain?

3. What actions or considerations has the U.S. government taken to reduce U.S. dependency on China for REEs?

Assumptions

Several assumptions will be utilized throughout this study. First, China will remain the top producer of REEs, and the U.S. will reduce its dependence on Chinese REEs. U.S. mining companies will continue to send mined rare earth concentrations to China for separation because of China's higher throughput capacity and effective refinement process.

Second, the policies and vital interests of the U.S. will not alter assessments made in this study. The modernization of the Army will only accelerate and solidify the policies already set in place. Presidential Executive Order (EO) 13817 outlining the national strategy to ensure reliable supplies of critical minerals will remain in effect even after the 2020 election because of REE's importance not only to the DoD industrial complex but also in clean energy technology.

Third, the U.S.-Taiwan relationship will increase the tensions between China and the U.S., and a Chinese embargo on REE exports to the U.S. is possible. In July 2019, the Trump Administration approved the arms sales of Abrams tanks and Stinger missiles to Taiwan. China's Defense Ministry said Beijing was "firmly opposed to U.S. arms sales to

Taiwan and U.S. military contact with Taiwan.”⁵⁵ If China decides to use REEs as an economic weapon against the U.S., it will severely hinder U.S. defense production line.

Fourth, this study will not consider the economic effects of worldwide pandemics. The coronavirus, also known as COVID-19, will not pose economic security issues to the U.S. industry and REE supply chains. The research will assume the supply and demand of REE will remain the same as before the COVID-19 outbreak on December 31, 2019 in Wuhan, China.

Definitions and Terms

Many REEs are not independent elements easily pulled out of the earth like gold. REEs are often clustered with other minerals. Mineral commodities produced can indicate their relative economic importance at that site.⁵⁶ Byproduction is produced in addition to the principal product and can be an unintended outcome of refinement of materials. Byproduction is often used interchangeably with coproduction to describe a detailed study of the future availability of natural resources to meet supply demands. According to the USBM dictionary of mining and mineral terms published by the

⁵⁵ Ryan Browne, “U.S. approves major arms sale to Taiwan amid trade tensions with Beijing,” *CNN News*, July 8, 2019, <https://www.cnn.com/2019/07/08/politics/us-arms-sale-taiwan/index.html>.

⁵⁶ U.S. Department of the Interior, U.S. Geological Survey (USGS), *Critical Mineral Resources of the United States—Economic and Environmental Geology and Prospects for Future Supply*, ed. Klaus J. Schulz, John H. DeYoung, Jr., Robert R. Seal II, and Dwight C. Bradley, Professional Paper 1802, U.S. Geological Survey, 2017, <https://doi.org/10.3133/pp1802>, A5.

American Geological Institute in 1997, added a definition of “coproduct” that is cross-referenced to the definition of “byproduct.”⁵⁷

REEs are extracted from mineral deposits and can originate from reserves. Reserves is classified as part of the reserves base, which could be economically extracted or produced at the time of determination.⁵⁸ Inferred resources are estimates based on geological evidence and may or may not support estimated figures by samples or measurements. Many inferred estimates are the basis for Preliminary Economic Assessments (PEA), which is typically the first step for mining companies to gain interest in their proposal. PEAs are covered in Chapter Two.

Limitations, Delimitations, and Scope

The limitation of this study is the time available to conduct open-source research. With such a short period of time and the volatile rare earths market trends, it may limit the applicability of the research finding for defense purposes. The availability and access to information may also affect the study because the newly established Combat Capabilities Development Command may not be able to share information due to its sensitivity and higher classification. Additionally, information from REE companies may also be unavailable for public access, especially if the company is private. The information would only be available to certain investors.

⁵⁷ USGS, *Critical Mineral Resources of the United States*, A5.

⁵⁸ U.S. Department of the Interior, U.S. Geological Survey (USGS), *Mineral Commodity Summaries 2020*, U.S. Geological Survey, 2020, <https://doi.org/10.3133/mcs2020>, 195-196.

Previous experiences working with open-source research as an analyst can bring certain biases to the study. The researcher's limited experience in conducting original research may affect the study as well through personal biases as a military member. Although every effort will be made to be objective, these biases can reflect the researcher's point of view. To mitigate this, the researcher will outline strict guidelines covered in Chapter Three. Additionally, the researcher is independent of any companies mentioned in this study. Therefore, the researcher has no vested interest in any REE company. The researcher will only cover the facts discovered in this study.

Coordination for a federal approach on REEs lacks a unified opinion on whether every rare earth element is considered critical or strategic for economic or national security purposes.⁵⁹ Therefore, this study will address REEs as a group and cite some elements commonly used for defense purposes. The study also subdivides REEs into light and heavy REEs (see Chapter Two). Also, the DoD does not regularly publish REE consumption rates, except in 2012 when the head of Industrial Policy (INDPOL) stated the DoD uses less than 5 percent of rare earths.⁶⁰ Thus, facts and figures will display the disproportionate dominance of China in the rare earths industry through quantifiable data and not include DoD consumption rates.

⁵⁹ U.S. Library of Congress, Congressional Research Service (CRS), CRS Report R41744, *Rare Earth Elements in National Defense: Background, Oversight Issues, and Options for Congress*, by Valerie Bailey Grasso (Washington, DC: Office of Congressional Information and Publishing, September 17, 2013), 24.

⁶⁰ Gopal Ratnam, "Rare Earth Shortage Would Spur Pentagon to Action," *Bloomberg News*, April 3, 2012, <https://www.bloomberg.com/news/articles/2012-04-04/rare-earth-supplies-in-u-s-to-meet-defense-needs-pentagon-says?sref=38hIy4be>.

This thesis confines itself to short- and long-term solutions for upstream and midstream supply chain of REEs (definitions are covered in Chapter Two). The study explores existing active mines and advanced mining exploration projects with plans for a separation plant compliant with the National Technology and Industrial Base (NTIB). Chapter Two covers separation facilities. The NTIB consists of companies or legal entities located in the U.S., Canada, Australia, or the United Kingdom. The Fiscal Year (FY) 2017 National Defense Authorization Act encourages increased integration between NTIB countries. Currently, there are no REE mining companies with separation facilities in the United Kingdom. So, the study will focus primarily on the U.S., Canada, and Australia.

There are several delimitations the study will follow. First, the study will not undertake the monumental task of evaluating all NTIB deposits or policies regarding REEs. Second, the study will not conduct an in-depth analysis of the entire REE supply chain. Instead, the study will focus primarily on upstream and midstream supply chain processes and opportunities. Third, the study will not attempt to determine which mining companies have the best economically viable REE resource or try to determine the best company. Instead, the study examines whether each company's supply chain is independent of China. The parameters and evaluation criterion are covered in Chapter Three. Fourth, this thesis will not conduct an in-depth analysis of rare earth metals and alloy making. While both REE metals and alloys are important defense and commercial needs, these subject areas require a separate study of their own. Fifth, the subject of downstream REE manufactured goods are too broad for this study to cover. Therefore, to narrow the scope, the study discusses two downstream manufactured key permanent

magnets to demonstrate China's ascendance. Finally, this study does not attempt to examine U.S. foreign policy toward China in detail. It mentions the U.S. relationships with Taiwan to show that there are significant points of contention between the U.S. and China, and that this contentious relationship raises the possibility that at some future time the PRC could halt all REE exports to U.S.

Chapter Conclusion

The next chapter discusses the pieces of literature examined for this study. The chapter defines REEs and covers the criticality of REEs for the U.S. economy and military. Then, the chapter explores the REE value supply chain and explains its importance to the DoD at each stage. Finally, the literature review will also identify and describe U.S. government actions to mitigate vulnerabilities through government agencies, studies, and articles.

CHAPTER 2

LITERATURE REVIEW

Introduction

By 2035, R&D programs will depend more on REEs to produce advanced high-tech platforms and systems. Enemy forces will use advanced Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance and “information technologies, lethal precision strike and area effect weapons, and the capacity to field first-rate technological innovations” against the U.S..⁶¹ A balance between industrial growth and stability must be sustained while promoting innovation to remain competitive with near peer threats. Even Secretary Esper noted the importance of R&D for the military through his statement made on February 2019:

We are doing our part to safeguard American innovation and reinvigorate our industrial base. Thanks to our largest Research and Development budget in 70 years, we are investing in cutting-edge technologies and accelerating the modernization of our force, while at the same time, divesting from legacy systems and re-investing those savings into hypersonic missiles, artificial intelligence, autonomous systems, and other game-changing technologies..⁶²

General Mark A. Milley, the Army Chief of Staff, echoes Secretary Esper’s statement by saying that the U.S. military must develop “weapons, combat vehicles, sustainment systems, and equipment that Soldiers need when they need it.”⁶³ This implicates more

⁶¹ JCS, *Joint Operating Environment 2035*, 15.

⁶² Esper, “As Prepared Remarks by Secretary of Defense Mark T. Esper at the Munich Security Conference.”

⁶³ Mark A. Milley and Mark T. Esper, “The Army Vision,” U.S. Army, June 2018, https://www.army.mil/e2/downloads/rv7/vision/the_army_vision.pdf.

funding for defense systems and weapons, which will rely heavily on REEs in order to be lighter, more compact, and more effective for combat. Therefore, it is imperative to maintain a steady supply stream outside of China in order to support the modernization of the military for future innovative defense products.

In order to reduce dependency on China, it is important to understand REE uses and the complex REE supply chain. This chapter will follow the secondary questions listed in the preceding chapter. First, the chapter covers the importance of REEs to the U.S. economy and military. Then, it explains what REEs are and China's disproportionate dominance across global reserve figures, mining production rates, and the comparison of REE composition. Then, the chapter describes the REE supply chain from upstream to downstream operations. By exploring each step of the supply chain, vulnerabilities will be identified as well as some NTIB opportunities for the U.S. Lastly, the chapter reviews U.S. government actions taken to secure the rare earth supply stream for national defense.

The Importance of REEs

Understanding the importance of REEs is not difficult when reviewing their endless utility. Rare earths have unique chemical properties that make them ideal for many commercial and military high-tech applications. Commercially, they are used most often as catalysts. For example, oil refineries use lanthanum-based catalysts as cracking agents to help refine fuel and increase production capacity. Automobiles use cerium-based catalytic converters for exhaust emission control, reducing toxic pollutants. Samarium oxides are used in infrared absorbing glass for nuclear reactors, safely

containing radioactive material. Neodymium compounds stabilize electricity through ceramic capacitors.⁶⁴ Cerium oxide, the most abundant REE, is widely used in precision glass polishing and decolorization of flat panel display screens.⁶⁵ Gadolinium enhances advanced imaging systems and optical properties in X-ray and magnetic resonance imaging scanning machines. Other common uses include metallurgical and alloy applications in permanent magnets of NdFeB and samarium cobalt (SmCo). These magnets are particularly important to green technology, including solar energy, wind turbines, and electric vehicles.

Militarily, the permanent magnets of NdFeB and SmCo provide strong demagnetization characteristics needed for high-speed, high-capacity weapons systems discussed further in this chapter. For example, the F-35 Lightning II aircraft, the top-tier stealth fighter jet designed to service the U.S. military, requires 920 pounds of rare-earth materials.⁶⁶ Without these rare earths, aircrafts would be heavier and less compact, most likely decreasing their maneuverability. Rare earth metals, alloys, and magnets are used in fin actuators to control the flight patterns in missiles of Precision Guided Munitions, making the system more precise and accurate for greater lethality.⁶⁷

⁶⁴ Cindy Hurst, “China’s Rare Earth’s Industry: What can the West Learn?” Institute for the Analysis of Global Security (IAGS), Washington, DC, March 2010, 35.

⁶⁵ Glass products have natural traces of iron and other impurities, which gives glass a green or brownish tint. Cerium oxide helps not only decolor the glass, but it also helps stabilize against high temperatures.

⁶⁶ CRS, CRS Report R41744, 5.

⁶⁷ Russell Parman, “An Elemental Issue,” U.S. Army, September 26, 2019, accessed February 24, 2020, https://www.army.mil/article/227715/an_elemental_issue.

Other military uses of REEs include digital displays and monitors. The phosphors from samarium, yttrium, and europium REOs are critical to track friendly forces on Joint Battle Command-Platforms. Lanthanum in night vision devices allows soldiers to effectively “own the night” and defeat the enemy. REEs are invaluable to the Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance Program, and units would not be able to command and control their units during combat operations effectively without their presence in key systems such as radio and satellite communications. Clearly, without REEs, producing high-tech systems will be difficult for the Defense Industrial Base (DIB) to properly equip the military.

REE Background

A Finnish chemist, Johan Gadolin, discovered the first rare earth element in 1794 when he received a unique black mineral from a Swedish army officer, Carl Axel Arrhenius, in the village of Ytterby, Sweden.⁶⁸ The material uncovered, later named yttrium, was an amalgam of intricate oxides tightly bonded together. Unusual to find in pure elemental form, rare earths are expensive and difficult to chemically isolate. Despite the name “rare earth,” REEs are more copious in the earth’s crust than silver, gold, or platinum. REEs exist on sandy beaches, rocks in the backyard, or as mining byproducts of copper, gold, uranium, phosphates, and iron.⁶⁹ The problem is whether the discovered

⁶⁸ Many sources credit Lieutenant Carl Axel Arrhenius as the discoverer of rare earth elements. See Chemistry Explained, “Johang Gadolin,” accessed May 12, 2020, <http://www.chemistryexplained.com/Fe-Ge/Gadolin-Johang.html>.

⁶⁹ U.S. Department of the Interior, U.S. Geological Survey (USGS), *Byproduct Metals and Rare-Earth Elements Used In the Production of Light-Emitting Diodes—*

mineral deposits have sufficient concentrations of REEs to be useful for mining and processing for industry products.

REEs are a group of 17 elements found on the Periodic Table of Elements (see figure 1). They consist of lanthanides (atomic numbers [nr] 57 through 71) plus yttrium (nr 39) and scandium (nr 21). Yttrium and scandium are grouped with REEs because of their similar chemical properties and generally being found within the same mineral deposits as the lanthanides.

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Figure 1. Periodic Table of Heavy and LREE

Source: Data from Secretary of Energy, *Report on Rare Earth Elements from Coal and Coal Byproducts: Report to Congress*, U.S. Department of Energy, January 2017, <https://www.energy.gov/sites/prod/files/2018/01/f47/EXEC-2014-000442> - for Conrad Regis, 3.

Overview of Principal Sources of Supply and Material Requirements for Selected Markets, by David R. Wilburn, Scientific Investigations Report 2012–5215, U.S. Geological Survey, 2012, <https://pubs.usgs.gov/sir/2012/5215/pdf/sir2012-5215.pdf>, 6.

These lanthanides appear in numerous mineral deposits, although, industrial grade ores typically derive from bastnaesite, monazite, and ion-absorption clay from China. Depending on the mineral, the metallurgical process for extracting REEs varies greatly. For instance, it is more challenging and expensive to extract REEs from bastnaesite and monazite ores than ion-absorption clays.⁷⁰ Ion-absorption clays are easily accessible through surface mining throughout multiple provinces in China. The clay is placed in an acid solution also known as leaching in order to isolate the preferred REE. On the other hand, bastnaesites and monazites must undergo a complicated multistep beneficiation and separation process discussed later in this chapter.

REEs can be broken down into light rare earth elements (LREEs) and heavy rare earth elements (HREE), assorted by their atomic weight (see Figure 1).⁷¹ Bastnaesite mostly contains LREEs, while monazites can contain a mixture of light and heavy REEs, and ion-adsorption clays are richer in HREEs. The largest concentrations of bastnaesite deposits reside in the U.S. and China, whereas monazite deposits are found in Australia, South Africa, China, Brazil, Malaysia, and India.⁷² Ion-absorption clays are only found in

⁷⁰ JinYang X., Aijun Lin, Xiao-Liang Li, Yiding Wu, Wenbin Zho, and Zhanheng Chen, “China’s ion-adsorption rare earth resources, mining consequences and preservation,” *Environmental Development* (March 19, 2013): 131-136, <http://dx.doi.org/10.1016/j.envdev.2013.03.006>.

⁷¹ Some sources categorize REEs into three categories: light, medium, and heavy. The medium REEs are Sm, Eu, Gd. However, most sources group REEs as light and heavy.

⁷² U.S. Library of Congress, Congressional Research Service (CRS), CRS Report R41347, *Rare Earth Elements: The Global Supply Chain*, by Marc Humphries

certain provinces in China and have not been discovered anywhere else on earth.⁷³ Still, HREEs exist in many different types of mineral deposits, but are not produced to the same capacity or scale as in China.⁷⁴

While both LREE and HREEs are important for military and commercial use, HREEs are more desirable for several reasons. REEs unique characteristics improve in magnetic and conductive qualities as the atomic number increases across the lanthanides family on the Periodic Table of Elements. Therefore, the heavier REEs have more applications and are higher in value than LREEs. Additionally, the increasing demand for clean energy products expects to outstrip supply of certain HREEs like dysprosium, which is used in permanent magnets. These permanent magnets are important for motors in electric vehicles. Many European countries announced bans on the sale of gasoline and diesel fueled vehicles as early as 2025.⁷⁵ Major automotive manufacturing companies declared aggressive electric vehicle production targets to cater to Europe's pledge to stop

(Washington, DC: Office of Congressional Information and Publishing, December 16, 2013), 9.

⁷³ X. et al., "China's ion-adsorption rare earth resources,"133.

⁷⁴ Peralkaline igneous systems are normally rich in HREEs. These systems can be found in Bokan Mountain, Thor Lake, and many other sources. See USGS, *Critical Mineral Resources of the United States*, O8-13.

⁷⁵ Many European countries plan to ban the sale of fossil fuel vehicles such as Norway, Germany, United Kingdom, and France. Seattle, Los Angeles, and California are also looking to ban gas and diesel cars in the near future. See Adamas Intelligence, "Rare Earths," Mkango Resources Ltd., accessed May 2, 2020, <https://www.mkango.ca/rare-earths/>.

global warming by supporting the Paris Climate Commitment.⁷⁶ Hence, the future supply-demand dynamic will increase the cost of HREEs as well as the deficits of rare earth metals.

Furthermore, the U.S. does not have a domestic active mine producing HREEs. The U.S. only has one active LREE mine in Mountain Pass, CA. When comparing ratios of REE deposits from active mines, China has higher quantities of HREEs than the U.S.⁷⁷ Figure 4 below displays the major differences in ore composition between LREEs and HREEs. As depicted, southern China has more concentrations of HREEs and a healthier assortment of light and heavy REEs.⁷⁸

⁷⁶ The Paris Climate Commitment is a legally binding global climate change agreement. 195 countries committed to reduce carbon emissions and the EU hopes to be climate neutral by 2050. See European Commission, “EU Climate action and the European Green Deal,” accessed May 20, 2020, https://ec.europa.eu/clima/policies/eu-climate-action_en.

⁷⁷ USGS, “Rare Earth Elements—Critical Resources for High Technology.”

⁷⁸ The DOE stated Y, Dy, Nd, Tb would become more critical in developing clean energy and potentially stronger magnets in the future. See Secretary of Energy, *Critical Materials Strategy*, U.S. Department of Energy, December 2011, <https://www.energy.gov/policy/downloads/2011-critical-materials-strategy>, 116.

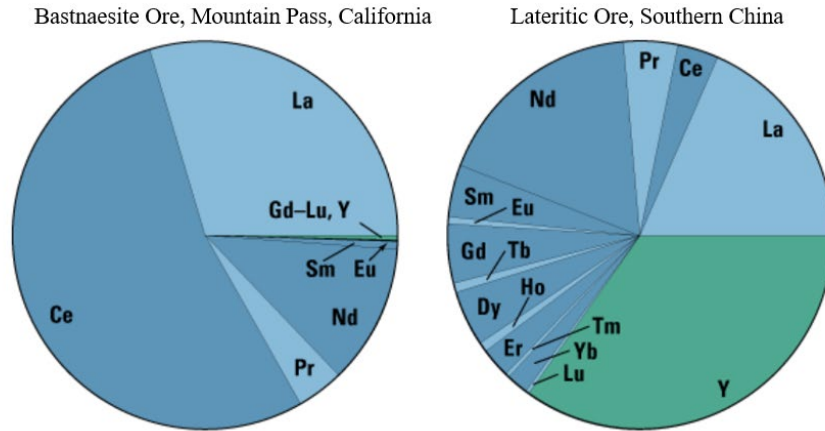


Figure 2. Proportions of Individual REE in Two Representative Ores

Source: Data from U.S. Geological Survey, “Rare Earth Elements—Critical Resources for High Technology,” by Gordon B. Haxel, James B. Hedrick, and Greta J. Orris, Fact Sheet 087-02, 2002, <https://pubs.usgs.gov/fs/2002/fs087-02>.

NOTE: The bastnaesite ore, dominated by La, Ce, and Nd, LREE with Eu through Lu plus Y (HREE) totaling only 0.4%; and lateritic ion-adsorption ore, Y-dominated. Dark blue and light blue sectors represent lanthanides of even and odd atomic number. Yttrium is indicated by green.

Sources of REEs are geographically abundant all over the earth’s crust and many countries outside of China have REE reserves. There are an estimated 120 million metric tons of REE reserves worldwide. Of these, 44 million metric tons can be found in China, the largest estimate of any single country. Figure 3 below displays each country’s reserve estimate.⁷⁹

⁷⁹ Reserve estimates fluctuate depending on the feasibility of extraction, new technology, or when new deposits are discovered. In general, the reserves estimate give an indication of untapped, economically viable resources of a country. See USGS, *Mineral Commodity Summaries 2020*, 195-196.

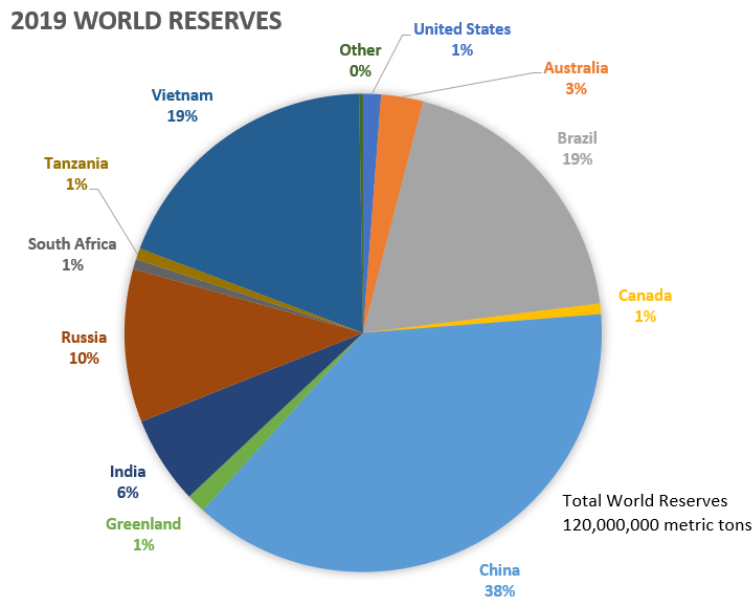


Figure 3. 2019 REE Reserves

Source: Created by author using data from U.S. Department of the Interior, U.S. Geological Survey, *Mineral Commodity Summaries 2020*, U.S. Geological Survey, 2020, <https://doi.org/10.3133/mcs2020>, 130-131.

Mining production rates portray a similar reality on REEs. China's sheer dominance is displayed through its 132,000 metric tons of rare earths mined in 2019, which is quintuple the REE production rate of the U.S. (see figure 4). China's production dwarfs every other country involved in the production of REEs. The figure is also 10 percent higher than the production rate in 2018, demonstrating their growth and capacity to keep up with global demands.⁸⁰ Unfortunately, with China's high production rates and minimal options for REE suppliers, the U.S. now relies entirely on foreign imported

⁸⁰ Bloomberg News, "Chinese rare earth magnet producer to expand as EV demand booms," *Bloomberg*, 24 June 2019, <https://www.mining.com/web/chinese-rare-earth-magnet-producer-to-expand-as-ev-demand-booms>.

REEs and 81 percent comes from China.⁸¹ This highlights a substantial vulnerability in ensured access to critical REEs for the U.S. economy and defense purposes.

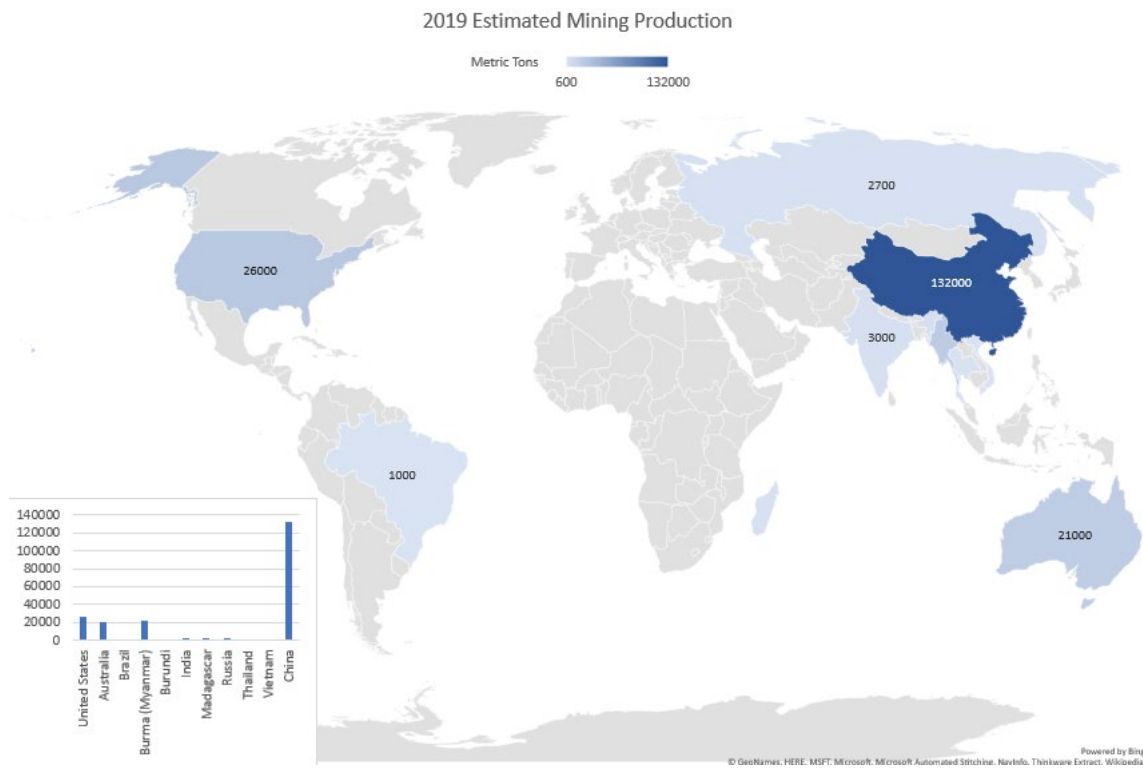


Figure 4. 2019 Estimated Mining Production

Source: Created by author using data from U.S. Department of the Interior, U.S. Geological Survey, *Mineral Commodity Summaries 2020*, U.S. Geological Survey, 2020, <https://doi.org/10.3133/mcs2020>, 130-131.

While the U.S. is increasing its REE mining production, there are several key considerations. First, all mined REEs from the U.S. originate from one source: Mountain

⁸¹ USGS, *Mineral Commodity Summaries 2020*, 130-131.

Pass, CA. Second, the mining production for the company began in 2018 and their production rate increased by 44 percent in 2019. China further refines and chemically separates all 26,000 metric tons of REE concentrates mined at Mountain Pass. Third, Mountain Pass mostly produces LREEs.

Rare Earth Supply Chain

China clearly dominates the REE market, not just in mining but in separation, processing, and manufacturing. A review of the REE supply chain demonstrates its complex nature and the urgent need for the U.S. to secure an REE supply chain that is independent from China. In April 2010, the Government Accountability Office (GAO) presented supply chain vulnerabilities to Congress, showing that nearly all the rare earths produced were mined, processed, refined, and manufactured in China.⁸² The lack of diversification of supply and production of rare earth materials poses a significant threat to the DIB, leaving the U.S. susceptible to supply chain disruption and a stoppage of defense production (see figure 4).

⁸² U.S. Government Accountability Office (GAO), GAO-10-617R, “Rare Earth Materials in Defense Supply Chain,” (Briefing for Congressional Committees, PowerPoint Presentation, April 1, 2010), <https://www.gao.gov/products/GAO-10-617R>, 19.

Rare Earth Supply Chain of Permanent Magnets

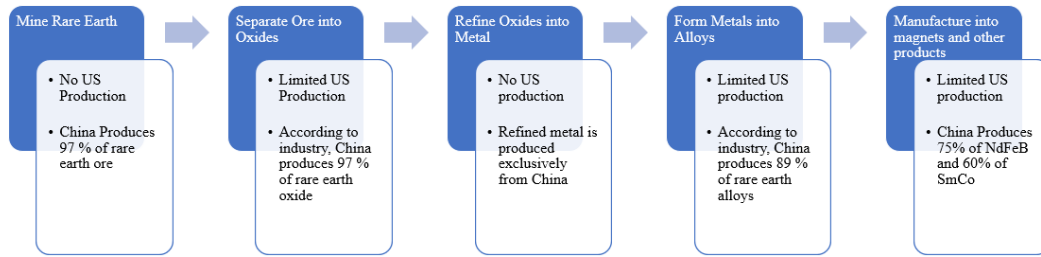


Figure 5. Rare Earth Supply Chain of Permanent Magnets

Source: Created by author using data from U.S. Government Accountability Office (GAO), GAO-10-617R, “Rare Earth Materials in Defense Supply Chain,” (Briefing for Congressional Committees, PowerPoint Presentation, April 1, 2010), <https://www.gao.gov/products/GAO-10-617R>, 19.

The supply chain begins with searching for viable mineral deposits for REEs through exploration. Once a mineral deposit is found, the ore undergoes a multistep process to retrieve the element desired for manufactured products. The rare earth production process includes mining, beneficiation, separation, processing, and manufacturing rare earths into end-use items.⁸³ Mining and beneficiation are known as the upstream process of the REE supply chain, while separation and processing are the

⁸³ The GAO breaks down the stages of production into mining, separating, refining, alloying, and manufacturing. However, the term “separation” is generally used by mining companies to describe what the GAO refers to as “refining”. In this section, “beneficiation” is used instead of the GAO’s definition for producing REE concentrates. See GAO, GAO-10-617R, 19.

midstream (refer to Figure 6). The last stage, manufacturing, is considered a downstream process, according to the DOE.⁸⁴

The next few sections of this chapter will describe the exploration, upstream, midstream, and downstream processes of the rare earth supply chain. Exploration discusses the difficulties and risks associated with searching for feasible rare earth deposits within the NTIB. The following sections mention active mining projects and advanced mining projects as probable prospects. The upstream process covers the mining and beneficiation process for most REE mining companies. The overall process demonstrates the difficulty of extracting rare earths from its mined ore and sometimes produces radioactive material, harmful to the environment. Midstream operations involve separation and processing. This subsection will identify how separation and processing of REEs are dominated by China. Finally, the downstream process compares two key permanent magnets the DoD is highly dependent on for defense purposes. An exploration of the two magnets will demonstrate its importance, effect on the supply chain, and China's dominion over REE manufacturing.

⁸⁴ U.S. Department of Energy (DOE), Office of Energy Efficiency & Renewable Energy, *Critical Materials Rare Earths Supply Chain: A Situational White Paper*, U.S. Department of Energy, April 2020, [https://www.energy.gov/sites/prod/files/2020/04/f73/Critical Materials Supply Chain](https://www.energy.gov/sites/prod/files/2020/04/f73/Critical_Materials_Supply_Chain), 6.

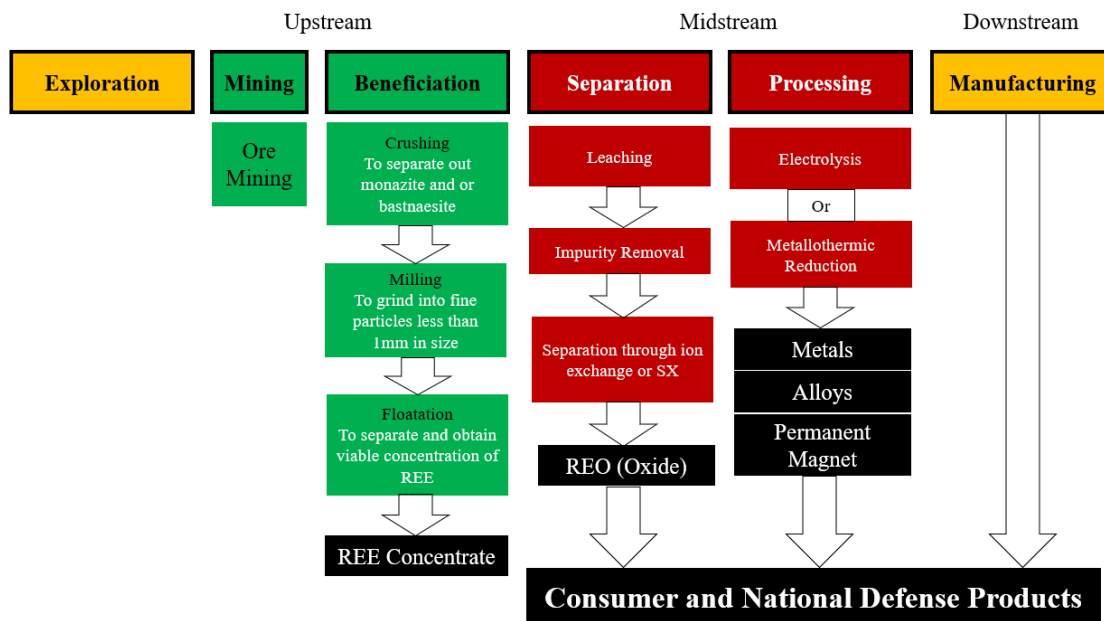


Figure 6. Rare Earth Element Value Chain

Source: Created by author using data from Secretary of Energy, *Report on Rare Earth Elements from Coal and Coal Byproducts: Report to Congress*, U.S. Department of Energy, January 2017, [https://www.energy.gov/sites/prod/files/2018/01/f47/EXEC-2014-000442 - for Conrad Regis, 4](https://www.energy.gov/sites/prod/files/2018/01/f47/EXEC-2014-000442_-_for_Conrad_Regis_4).

Exploration

Exploration of new deposits is an uncertain field with high capital risks. The explorer looks for “targeted type, size, and quality with the least amount of expense.”⁸⁵ Any prospect mine that fall under the NTIB may undergo multiple periods of exploration from various qualified scientists and engineers for many decades. Exploration studies are

⁸⁵ U.S. Department of the Interior, U.S. Geological Survey (USGS), *The Principal Rare Earth Elements Deposits of the United States—A Summary of Domestic Deposits and a Global Perspective*, by Keith R. Long, Bradley S. Van Gosen, Nora K. Foley, and Daniel Cordier, Scientific Investigations Report 2010–5220, U.S. Geological Survey, 2010, <https://pubs.usgs.gov/sir/2010/5220>, 21–23.

usually limited by two main factors: budget-cycles and time. Despite these hurdles, there are several advanced REE exploration projects and resources in Alaska, Nebraska, Texas, Wyoming, and parts of Canada (see Table 1). In North America, rare earth resources were estimated at 2.7 million tons in the U.S. and more than 15 million tons in Canada, according to the USGS.⁸⁶ However, many mining projects are prospective and resource estimates are inferred based on geological data collected.

⁸⁶ USGS, *Mineral Commodity Summaries 2020*, 130-131.

Table 1. North American Advance REE Exploration Projects and REE Type

Deposit	Location	REE Type
Bokan Mountain	Alaska, U.S.	LREE, HREE
Bear Lodge	Wyoming, U.S.	LREE, HREE
Elk Creek	Nebraska, U.S.	REE resources exist, but are not estimated
Round Top	Texas, U.S.	HREE plus other strategic metals
Clay-Howells project	Ontario, Canada	LREE some HREEs
Eco Ridge Mine	Quebec, Canada	Primarily U and Nd but has other HREEs
Hoidas Lake deposit	Saskatchewan, Canada	Ce, Pr, and Nd, with minor Sm and trace Dy
Kipawa	Quebec, Canada	La, Ce, Nd, Pr, HREE
Lavergne-Springer Property	Ontario, Canada	La, Ce, Nd, Y
Montviel project	Ontario, Canada	Pr, HREE
Nechalacho project (Thor Lake)	Northwest Territories, Canada	La, Ce, Pr, Nd, HREE
Two Tom	Newfoundland and Labrador, Canada	La, Ce, Pr, Nd, Sm, HREE

Source: Created by author using data from U.S. Department of the Interior, U.S. Geological Survey, *Critical Mineral Resources of the United States—Economic and Environmental Geology and Prospects for Future Supply*, ed. Klaus J. Schulz, John H. DeYoung, Jr., Robert R. Seal II, and Dwight C. Bradley, Professional Paper 1802, U.S. Geological Survey, 2017, <https://doi.org/10.3133/pp1802>, O14-O16, and other sources. NOTE: [Ce, Cerium; Dy, dysprosium; HREE, heavy rare earth element; La, Lanthanum; LREE, light rare earth element; Nd, neodymium; Pr, praseodymium; REE, rare-earth element; Sm, Samarium; U, uranium; Y, Yttrium].

While there are many opportunities to mine rare earths, establishing new mines in the U.S. is a long and expensive process. Prolonged lead times, trade policies, permits, and environmental considerations hamper new mines and companies from ever reaching

commercial production.⁸⁷ One example that requires significant time is the Environmental Impact Statement from the U.S. Forest Service (USFS), which on average takes 647 days to complete.⁸⁸ On top of the Environmental Impact Study, mine building requires permit approvals from the county, state, and federal agencies. Extensive trenching, drilling, and sampling from qualified scientists and engineers determines the richness of the minerals and is outlined in a technical study. A PEA is required to even be considered for financing or receive U.S. regulatory approval. If the PEA demonstrates a positive impact study, then the project may move ahead with a Preliminary Feasibility Study (PFS) plan of action, construction plan, engineering design, and construction decision.⁸⁹ Based on a study conducted by the USGS, the initial production for the mines can stretch from 5 to 50 years, permitting to initial production 1 to 7 years, and ramp-up times can range from 3 to 42 months.⁹⁰ Even if mining operations commence, many mines fail due to lower than expected ore grades or metallurgical procedures that do not work as anticipated.⁹¹

⁸⁷ USGS, *The Principal Rare Earth Elements Deposits of the United States*, 21-23.

⁸⁸ U.S. Department of Agriculture, Forest Service, “National Environmental Policy Act (NEPA) Compliance,” Proposed Rules, *Federal Register* 84, no. 114 (June 13, 2019): 27545, 2.

⁸⁹ Feasibility Studies can be either Preliminary or Final. Most companies do not require a final feasibility study unless there is significant debt involved. See USGS, *The Principal Rare Earth Elements Deposits of the United States*, 22-23.

⁹⁰ Ibid.

⁹¹ Ibid.

Only a handful of advanced mining exploration projects in North America have completed their technical studies and have had success in their pilot separation facility. Some examples include Bear Lodge Mountain in Wyoming, Bokan Mountain in Alaska, and Round Top in Texas. Bear Lodge Mountain is owned by Rare Element Resources, which is rich in HREEs in their deposits. Bokan Mountain also has HREE deposits and is owned by Ucore Rare Metals. Round Top is owned by Texas Mineral Resources Corporation and contains LREE and HREEs as well as other critical minerals based on their technical study. Canada also has REE deposits located in Saskatchewan, Northwest Territories, Ontario, Quebec, Newfoundland, and Labrador. One advanced mining exploration project in Canada is near Thor Lake (Nechalacho), Northwest Territories. Avalon Rare Metals Inc. operates the Nechalacho project. The deposit is rich with HREE based on a conducted feasibility study.⁹²

Upstream: Mining and Beneficiation

Between exploration and upstream stages of the supply stream, the upstream stage is the most time-consuming process. Establishing mining operations and perfecting metallurgical processes requires technical expertise and significant capital. The time required to develop new sources is slow to respond to market demands even when the

⁹² Avalon Rare Metals. “Avalon Announces Results of Positive Feasibility Study for the Nechalacho Rare Earth Elements Project,” News Release No. 13-03, Avalon Rare Metals Inc., Toronto, Ontario, Canada, April 17, 2013.

industry is operating efficiently.⁹³ Once a mine is at operating capacity, the mine must scale its operations to the needs of the market.

First, ore deposits with appropriate rare earth concentrations also known as ore grades are dug from an open pit or underground mine.⁹⁴ The higher the ore grade in a deposit, the better chance of profitability of a project. Economically viable quantities often mean mining large volumes of ore deposits. After ore mining, companies' beneficiate the ores at the mining site since it is not cost-effective to ship ore deposits for further processing.

The beneficiation process is where the ore deposit is turned into ore concentrates. This is where low-value minerals are removed to produce a higher-grade rare earth concentrate. The beneficiation process for common ore deposits like monazites and bastnaesite includes crushing, milling, and flotation (refer to figure 6). The mineral deposits are crushed into gravel-sized pellets. Then, the pellets are milled into silt or dust, including metals and radionuclides. The silt is placed through a flotation process to separate nonessential materials from desired REE concentrates. There are other separation techniques used, such as optical sorting, gravity and magnetic separation but flotation is most widely used in the REE industry. The disadvantage of processing large volumes of ores is its low recovery rates. Consequently, beneficiation tends to be an

⁹³ Secretary of Energy, *Critical Materials Strategy*, 56.

⁹⁴ Ore deposits has sufficient concentrations for exploitation while mineral deposits are the natural occurrence of a useful mineral. See Britannica Academic, "Mining," accessed May 21, 2020, <https://0-academic-eb-com.mwrlibrary.armybiznet.com/levels/collegiate/article/mining/110656>.

expensive upstream process. The metallurgy process must be tested and perfected to produce worthwhile quantities.

Currently, there are two active mining companies using this beneficiation process within the NTIB that produce industrial quantities of REEs: Mount Weld in Australia and Mountain Pass (refer to REE Background in this chapter). The Lynas Corporation, the owner of Mount Weld, provides a supply chain easily traceable and transparent to consumers. Mount Weld has one of the highest REE grades in the world and produces mostly LREEs.⁹⁵ Lynas Corporation differs from Mountain Pass operations in that it controls upstream production and a part of their midstream process of separation in Malaysia.

Midstream: Separation and Processing

Most of the world depends heavily on China for their midstream separation and processing of rare earths. Since Deng Xiaoping's economic reform, the lowered labor costs and initial relaxed environmental laws gave China the economic competitive edge in the REE industry. NTIB companies piecemealed operations offshore and subsequently lost most of their expertise and knowledge of separation and processing of rare earths. Moreover, China filed over 25,911 rare earth-related patents compared to 9,810 from the

⁹⁵ Lynas Rare Earths Ltd., "Lynas Rare Earths," accessed April 2, 2020, <https://www.lynascorp.com>.

U.S. as of October 2018.⁹⁶ Some of the patented intellectual property includes separation and refinement processes that China improved techniques down to an exact science.⁹⁷

The first step of separation pertains to the refinement of REE concentrates through leaching and the removal of impurities to create REOs. This can be achieved through ion exchange or solvent extraction (SX). There are other novel techniques of separation, but SX is commonly used and generally accepted in the industry.⁹⁸ A separation plant producing multiple REOs may have hundreds of stages to achieve the industry-standard desired purity level of 99.5 percent. The disadvantages of establishing a separation plant are the vast amounts of solvents required, the constant chemical adjustments based on the concentrate, and the high capital cost of establishing a chemical facility for REE separation. Based on a comparative study published by GeoMegA, a

⁹⁶ Eric Ng, “China’s war chest of rare earth patents give an insight into total domination of the industry,” *South China Morning Post*, July 20, 2019, <https://www.scmp.com/business/companies/article/3019290/chinas-war-chest-rare-earth-patents-give-insight-total>.

⁹⁷ International patents are difficult to enforce in certain countries. Generally, they are enforceable in China, Japan, South Korea, the EU and the United States. Patents typically lasts anywhere from 10 to 15 years. Licensing and royalties can be expensive for REE companies using patented intellectual property. See U.S. Patent and Trademark Office, “International Patent Cooperation,” accessed May 20, 2020, <https://www.uspto.gov/patents-getting-started/international-patent-cooperation>.

⁹⁸ Extraction chromatography is used to separate HREE into high purity REEs where it uses the selectivity of solvent extraction and chromatographic columns. See Dehzi Qi, “Ion-Exchange and Extraction Chromatography Separation of Rare Earth Elements.” *Hydrometallurgy of Rare Earths* (2018): 631-669.

Canadian company involved in recycling and refinement of rare earths, the cost to establish a separation plant can range from U.S. \$49 million to 498 million.⁹⁹

Additionally, the waste left behind from extracted REEs called tailings often contain radioactive content. This is one unintended consequence of separating REEs: it can produce the byproduct of thorium and uranium. Thorium is associated with separating monazites, though thorium coexists in bastnaesite and other mineral deposits in much smaller quantities. Due to environmental concerns, the U.S. does not mine monazites, although companies and government agencies are exploring this option.¹⁰⁰

The removal and disposal of thorium is a costly problem for mining companies, which Lynas is experiencing in its separation Kuantun Plant in Malaysia. Malaysian citizens protested against Lynas Corporation for the environmental impacts of separation and subsequently caused a decline in revenue. This separation facility provided consumers a non-Chinese solution to meet high global supply and demand. Malaysia recently approved a three-year license to allow the processing of rare earths at the Kuantan plant, pending the creation of a permanent waste disposal facility by July 2023.¹⁰¹ Lynas is also entering a joint-venture with Texas-based Blue Line Company for

⁹⁹ GeoMegA, “REE Separation,” accessed March 2, 2020, <https://ressourcesgeomega.ca/existing-technology>.

¹⁰⁰ CRS, CRS Report R41347, 9.

¹⁰¹ Aby Jose Koilparambil, “Lynas half-year profit plunges on Malaysia expenses amid weak market,” *Reuters*, February 27, 2020, <https://www.mining.com/web/lynas-half-year-profit-plunges-on-malaysia-expenses-amid-weak-market/>.

a HREE separation plant.¹⁰² The DoD is funding Texas-based Blue Line's pilot program for a HREE separations facility in the U.S.¹⁰³ The company will focus on separating two key elements important to defense equipment: dysprosium and terbium.

On the other hand, Mountain Pass' bastnaesite ore has a low-thorium content and is more environmentally friendly. However, the bastnaesite ore concentrate from Mountain Pass is not separated in U.S. Mountain Pass ships REE concentrates to China for additional separation. MP Materials plans to recommission an old separation facility on-site to increase their REO finishing capacity. Most of the facility was erected before Molycorp's, the previous owner of Mountain Pass, bankruptcy. MP Materials Co Chairman, Jim Litinsky, states it is a state-of-the-art facility and will be the largest of its kind.¹⁰⁴ Once the company restarts the separation facility, MP Materials will be the only North American company able to mine and refine their REOs independent from China.¹⁰⁵

¹⁰² Georgia Williams, "Rare Earths Outlook 2020: Trade War to Dominate Supply and Demand," *Rare Earth Investing News*, December 26, 2019, <https://investingnews.com/daily/resource-investing/critical-metals-investing/rare-earth-investing/rare-earth-outlook/>.

¹⁰³ Eric Hoover, Program Manager of the Industrial Base Analysis and Sustainment, phone interview with author, May 1, 2020.

¹⁰⁴ Jim Litinsky, "Co-chair of America's only rare earth mineral mine discusses China's threat," interview by Andrew Ross Sorkin, *CNBC*, May 30, 2019, <https://www.cnbc.com/video/2019/05/30/rare-earth-mining-china-trade-mp-materials-squawk-box.html>.

¹⁰⁵ MP Materials is increasing finishing capacity and perfecting their separations process. The company has not officially published the restart schedule of their separations facility.

One major problem with the midstream stage is the lack of diversification of REO suppliers. Even today, China dominates this arena of rare earth processing specifically in REE metals and alloys (see Figure 5). Midstream and downstream companies revert to purchasing REOs from China due to their great abundance and are generally lower cost. The final REO products are normally iron-gray to silvery lustrous metals that are soft, malleable, and ductile. REOs are the most stable as an oxide. However, the conversion of REOs to metals is a difficult process when removing the oxygen from the compound.¹⁰⁶ Metallurgical processes typically used are electrolysis and metallothermic reductions. Then, the metals are processed into alloys for magnet production and other end-items (see figure 6).

Very few companies can compete with China's industrial production of rare earth metals. Many companies fall into bankruptcy because they are unable to compete with China's lower pricing in the volatile rare earth market. One U.S. Company, Eutectix, has managed to stay afloat and even purchase other American companies to produce in the U.S. The company acquired two companies that formerly produced rare earth alloys on an industrial scale. The first company, Great Western Minerals Group Ltd., manufactured rare earth-based alloys, batteries, and high purity metals in Troy, Michigan until 2014 and went bankrupt in 2015. The second company, Molycorp Metals and Alloys, also manufactured magnet alloys, including SmCo alloy powders and NdFeB magnet powders

¹⁰⁶ Nagaiyar Krishnamurthy and Chiranjib Kumar Gupta, *The Extractive Metallurgy of Rare Earths* (Boca Raton, FL: CRC Press, 2016), 333-339.

until 2015 in Tolleson, AZ.¹⁰⁷ With both facilities under Eutectix, the company now makes high purity alloy products, vital for commercial and military applications. The company does have the capability to produce alloys, but most of the manufacturing moved to China or Japan. According to the company, Eutectix is the only manufacturer in the U.S. with strip cast alloy production equipment.¹⁰⁸ Another company able to produce REE alloys is Less Common Metals in the United Kingdom.

Downstream: Manufacturing

There are endless products that contain REEs to improve their function. Processed REE alloys and metals have an important role in many finished goods and end-item products. This section only focuses on two of these products, the permanent magnets that are so important to the defense industry: SmCo and NdFeB. To make these magnets, companies use alloy blocks or rods and grind them into the desired shape and size. After the item is complete, the item is electro-magnetized. Depending on size, some magnets are electro-magnetized on site because they are nearly impossible to pull apart.¹⁰⁹ For

¹⁰⁷ In 2016, Eutectix acquired Molycorp Metals and Alloys. See Eutectix, “Company History,” accessed May 20, 2020, <https://eutectix.com/about/company-history/>.

¹⁰⁸ Bob Russotti, “Docket DOC 2017-0003, Administration Report on Significant Trade Deficits,” *Eutectix* (blog), May 10, 2017, <https://eutectix.com/>; Jason Clune, Chief Marketing officer of Eutectix, email with author, May 12, 2020.

¹⁰⁹ Jody Shackelford, “How Magnets are Made in Arkansas - How It’s Made Arkansas Style!” video, June 3, 2011, <https://www.youtube.com/watch?v=wjZ1qxeYX5Q>.

example, when samarium is combined with cobalt, it has the highest resistance to demagnetization of any material.¹¹⁰

The SmCo magnet became crucial to the industrial complex in the 1970s, from small motors to radio towers. SmCo's characteristics amplified signals at microwave frequencies for high-performing radar, communications, and electronic countermeasure systems. Most of the cobalt used in SmCo originated from the Zaire, now known as the Democratic Republic of Congo. In 1978, Kantangan rebels based in Angola launched invasions into Zaire, causing instability and disruption in the cobalt supply chain for SmCo. The disruption in supply had catastrophic impacts on manufacturing companies, leading to increased prices, limited supply, and accelerating demand for cobalt.¹¹¹ Many factories and businesses that were dependent on cobalt to make SmCo were forced to shut down. This event highlighted a need for another permanent magnet, which was invented in 1982 by Dr. Masato Sagawa, a chemist from Japan, who sintered the permanent magnet of NdFeB (refer to Table 1).¹¹²

¹¹⁰ Hurst, "China's Rare Earth's Industry," 36.

¹¹¹ Scott A. Sibley, "Cobalt: A Strategic and Critical Resource for Industrialized Nations, Supplied By Developing Nations." *Natural Resources Forum* (October 1980): 402-413.

¹¹² Dr. Masagato Sagawa currently works for Daido Steel Company working on reducing dysprosium usage in NdFeB. He was able to sinter the magnet down to a smallest particle size about 70 percent and seeking to achieve 100 percent. See Underhill, "Inside Look at the Rare Earth Industries."

Table 2. History of Permanent Magnets of SmCo and NdFeB

Type of Magnet	Year	Inventor	MGOe	Withstand Temp.	Comments
SmCo5	1966	Dr. Karl J. Strnat	18-25		Created at U.S. Air Force Materials Laboratory at Wright-Patterson Air Force Base
Sm2Co17	1972	Karl J Strnat and Dr. Alden Ray of University of Dayton	33	550°C	Collaboration with other Research Institutions
NdFeB	1982	Dr. Masato Sagawa of Sumitomo	59.5		Independently produced

Source: Created by author using data from Magnet Energy Corporation.

NOTE: MGOe is a unit of measure to describe the stored magnet power, magnet performance, or maximum energy product. 1 MGOe is approximately equal to 7957.74715 Joule per cubic meter.

The NdFeB magnets have their own unique characteristics (refer to table 1).

These magnets are typically used for systems requiring strong magnetic power such as high-performance motors, sensors, switches, and particle accelerators.¹¹³ Their magnetic performance capability allows for the miniaturization of the items used in technology.

One common use for NdFeB are in cell phones to create vibrations and sounds using this tiny magnet.¹¹⁴ As mentioned earlier, NdFeB magnets are used in clean energy technology. In fact, Tesla, an electric car manufacturing company, shifted to neodymium

¹¹³ Integrated Magnets, “Neodymium (NdFeB) Magnets,” accessed May 2, 2020, <https://www.intemag.com/neodymium-magnets>.

¹¹⁴ Underhill, “Inside Look at the Rare Earth Industries.”

magnetic motors in their Model 3 Long-Range car and purchased over 4 million pounds of automotive parts from China and Japan in 2018.¹¹⁵

Today, China produces more than 90 percent of the world's permanent rare-earth magnets and has further indicated plans to restrict exports to the U.S.¹¹⁶ The country produced about 160,000 tons of NdFeB in 2018. NdFeB's importance is expected to grow with the need for clean energy for wind turbines and electric vehicles. According to a senior analyst at metals consultancy Roskill, David Merriman:

Global demand of 31,700 metric tons for neodymium [in 2017] already outstripped supply by 3,300 metric tons. Demand was expected to climb to 34,200 metric tons [in 2018] and 38,800 metric tons in 2019, leaving larger deficits.¹¹⁷

This situation presents an issue not only for the global supply of NdFeB but for U.S. defense uses as well. It is problematic for two reasons. First, the DoD consumed 175 tons of NdFeB in 2011, an amount which has since increased. With an increase in demand, supply for these magnets will be short. Second, more than 80 percent of the neodymium

¹¹⁵ Adam Isaak, "A rare metal called neodymium is in your headphones, cellphone and electric cars like Tesla's Model 3 — and China controls the world's supply," *CNBC*, October 28, 2018, <https://www.cnbc.com/2018/10/18/neodymium-china-controls-rare-earth-used-in-phones-electric-cars.html>.

¹¹⁶ Bloomberg News, "How China Overpowered the U.S. to Win the Battle for Rare Earths," *Bloomberg*, June 10, 2019. <https://www.bloomberg.com/news/articles/2019-06-10/china-s-grip-on-rare-earths-began-with-a-decision-30-years-ago?sref=38hIy4be>.

¹¹⁷ Pratima Desai, "Tesla's electric motor shift to spur demand for rare earth neodymium," *Reuters*, March 12, 2018, <https://www.reuters.com/article/us-metals-autos-neodymium-analysis-idUSKCN1GO28I>.

used to develop NdFeB comes from China.¹¹⁸ A halt on neodymium production in metals, alloys, and magnets would severely impact the U.S. economy and defense production.

When comparing the two magnets, NdFeB has a stronger magnetic field at room temperature. However, SmCo provides greater magnetic stability in higher temperatures, making them ideal for motors, generators, and actuators. One American company, Electron Energy Corporation, developed a series of SmCo magnets able to operate at 550°C with the assistance of DoD funding. The company still produces SmCo and NdFeB magnets on a small scale. However, the company receives a majority of its raw materials from China.¹¹⁹

Other magnet companies producing on a smaller scale include AZ Industries, Inc. and Arnold Magnetics. These manufacturing companies can produce Defense Federal Acquisition Regulation Supplement (DFARS) compliant magnets. DFARS ensures REE alloys do not originate from China, North Korea, Iran, or Russia. However, the REOs used to produce REE alloys can derive from China. Typically, government-related projects require DFARS compliant products to ensure the transparency of its supply chain for security reasons. According to the President of AZ Industries, Jim Adams, most of the

¹¹⁸ Isaak, “A rare metal called neodymium.”

¹¹⁹ Electron Energy Corporation marketing representative, telephone interview with author, May 10, 2020.

REE metals, alloy rods and blocks originate from China. Chinese raw materials are typically two times cheaper than DFARS compliant products..¹²⁰

Government Actions to Reduce Dependency on China

With the entire REE value supply chain being dominated by China, the U.S. government has been taking steps since the 2010 Senkaku Island incident to change this situation. Congress directed multiple government offices to gather information and produce assessments on the rare earth industry. Their findings were outlined in Section 843 of the FY 2011 National Defense Authorization Act. Section 843 also required the Secretary of Defense to assess the rare earth supply chain issues and address potential vulnerabilities. After a thorough review, the DoD reported that by 2012 U.S. domestic supply of REEs production in military applications could satisfy the defense procurement needs..¹²¹ The assessment was based on the 2011 defense requirements and did not take into account the growing dependence on REEs.

The U.S. government's interest in securing REE supply chains appears to have declined because REE prices stabilized after the WTO ruled that China needed to resume REE exportation. The demand for REEs also subsided, a fact that was covered in the 2013 Annual Industrial Capability Report to Congress. The decrease in demand was

¹²⁰ Jim Adams, President of AZ Industries, telephone interview with author, May 21, 2020.

¹²¹ Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, *Report to Congress: Rare Earth Materials in Defense Applications*, U.S. Department of Defense, March 2012, <https://www.hsdl.org/?abstract&did=704803>, 4.

attributed to three reasons: the introduction of substitutions, the reduction of REE usage based on the decrease of supply, and the increased production of new REE suppliers outside of China.¹²² The report also cited an increase in exploration for REEs to develop downstream capabilities. However, mining operations take years and even decades to produce a commercially viable product. Many of the 400 REE related companies failed because companies could not keep operations afloat during their exploration stage of establishing a viable mine.¹²³

Another action the government took included adding REEs to the National Defense Stockpile, managed by the Undersecretary of Defense for Acquisition, Technology, and Logistics and the Director of the Defense Logistics Agency.¹²⁴ In 2016, the Defense Logistics Agency included high-purity yttrium and dysprosium metal into the inventory. A few years later, raw materials such as dysprosium, yttrium, Ferro dysprosium, and europium were added into the stockpile. The National Defense Stockpile also initiated a program to recycle REEs from waste and investigate technologies to determine whether recycling is feasible in the U.S.¹²⁵

¹²² Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, and Office of the Deputy Assistance Secretary of Defense for Manufacturing and Industrial Base Policy, *Annual Industrial Capabilities Report to Congress for 2013*, U.S. Department of Defense, September 2016, [www.acq.osd.mil/mibp/resources/2013AIC RTC 10-03-16 - Public Unclassified.pdf](http://www.acq.osd.mil/mibp/resources/2013AICRTC10-03-16-PublicUnclassified.pdf), 19-21.

¹²³ Ibid.; Underhill, “Inside Look at the Rare Earth Industries.”

¹²⁴ CRS, CRS Report R45810, 7.

¹²⁵ Ibid.

Trump Administration EOs

Stockpiling and legislative actions were not enough to address upstream and midstream supply issues. With the USBM no longer in service, many companies claimed much of the mining technology, mine safety and health, and the mineral industry was lost.¹²⁶ Most of the USBM's Mineral Information Program transferred to the USGS' Mineral Resources Program as well as exploration technical reports. However, there still was a gap that needed to be filled. In reaction, the Trump Administration launched three main initiatives through EOs 13817, 13806, and 13807 to ensure the continued access to REEs based on the unwanted foreign dependency of critical minerals. Although North America does have significant REE deposits, many barriers continue to prevent miners and producers from supplying critical minerals the country needs.¹²⁷

EO 13817: Call for a Federal Strategy

In order to increase in private-sector domestic exploration, production, recycling, and reprocessing of critical minerals, President Trump signed EO 13817, *A Federal Strategy to Ensure Secure and Reliable Supplies of Critical Minerals*, on December 20, 2017. The Department of Commerce (DOC) developed a government-wide strategy to address the full supply chain of critical minerals. The actions outlined in the strategy cover short-term options, such as stockpiling and improving reliable trade options and

¹²⁶ DOE, *Critical Materials Rare Earths Supply Chain*, 8.

¹²⁷ U.S. President, Executive Order 13817, "A Federal Strategy to Ensure Secure and Reliable Supplies of Critical Minerals," *Code of Federal Regulations*, Title 3 (December 20, 2017).

long-term options, such as “catalyzing exploration, designing and constructing new mines, and re-establishing domestic downstream manufacturing supply chains.”¹²⁸ The strategy presents six Calls to Action:

1. The advanced transformational research, development, and deployment across critical mineral supply chains
2. Strengthen America’s critical mineral supply chains and DIB
3. Enhance international trade and cooperation related to critical minerals
4. Improve understanding of domestic critical mineral resources
5. Improve access to domestic critical mineral resources on federal lands and reduce federal permitting timeframes
6. Grow the American critical minerals workforce

The Cabinet-level Council of the National Science & Technology Council existing subcommittee on Critical & Strategic Mineral Supply Chains oversees the implementation of the Federal Strategy.¹²⁹ The subcommittee consists of members from multiple agencies, including DOE, Department of State, DoD, DOI, USFS, Environmental Protection Agency, and National Aeronautics and Space Association. With the diverse committee members, the subcommittee oversees the progress of “commodity-specific mitigation strategies addressing strategic vulnerabilities” and is able

¹²⁸ U.S. Department of Commerce (DOC), *A Federal Strategy to Ensure Secure and Reliable Supplies of Critical Minerals*, June 4, 2019, <https://www.commerce.gov/news/reports/2019/06/federal-strategy-ensure-secure-and-reliable-supplies-critical-minerals>, 14.

¹²⁹ DOE, *Critical Materials Rare Earths Supply Chain*, 3.

to update the critical minerals list depending on “supply, demand, concentration of production, and current policy priorities.”¹³⁰ The USGS and Bureau of Land Management produced a draft list of critical minerals with the cooperation of the DoD, DOE, Department of State, DOC, and other members of the National Science & Technology Council’s subcommittee on Critical & Strategic Mineral Supply Chains. The draft list specified 35 critical minerals vital to national security, but rare earths were listed as a group and not specific elements. After an extensive review, the DOI accepted and published the list on the Federal Register.¹³¹ The list aligned priorities across multiple agencies and allowed for the unification of efforts.

DOE

The Federal Strategy promotes the cross-coordination across multiple agencies. The DOE is one department that supports a large portion of the strategy like *Advanced Transformational Research, Development, and Deployment Across Critical Minerals Supply Chains* (Call to Action 1), *Strengthening America’s Critical Mineral Supply Chains and the DIB* (Call to Action2), and *Improving The Understanding Of Domestic Critical Mineral Resources* (Call to Action 4). The DOE recently announced their U.S. \$30 million funding for a sustainable critical-materials supply chain in the U.S., reducing

¹³⁰ DOC, *A Federal Strategy to Ensure Secure and Reliable Supplies of Critical Minerals*, 33.

¹³¹ Office of the Secretary, Department of the Interior (DOI), “Final List of Critical Minerals 2018,” *Federal Register* 83, no. 97 (May 18, 2018): 23295-23296, <https://www.federalregister.gov/documents/2018/05/18/2018-10667/final-list-of-critical-minerals-2018>.

costs and environmental impacts of production..¹³² The Under Secretary of Energy Mark W. Menezes stated,

Through these investments, DOE is advancing research, development, and deployment across the entire critical materials supply chain to help strengthen America's defense-industrial base. With a new federal strategy in place and an increased commitment to collaboration across sectors, we are well on our way to securing the country's supply of critical materials for generations to come..¹³³

The DOE, with its interagency partners, expects to complete technical and economic feasibility studies on unconventional sources like coal-based resources, mine tailings, and seawater deposits..¹³⁴ With new funding, the DOE's Office of Energy Efficiency and Renewable Energy and Office of Fossil Energy have important roles in improving the REE supply chain and R&D in rare earths. For example, Office of Fossil Energy funds the National Energy Technology Laboratory Feasibility of Recovering REE Program. This program develops technology for the recovery of REE from coal and coal ash. The DOE also intends to provide private industry access to computing capabilities and testing, validation support facilities, and lowering barriers to engage the government and academic laboratories, institutes, and organizations..¹³⁵ With an increase in projects,

¹³² U.S. Department of Energy (DOE), "Department of Energy Announces \$30 Million for Innovation in Critical Materials Processing Technologies," May 14, 2020, <https://www.energy.gov/articles/department-energy-announces-30-million-innovation-critical-materials-processing>.

¹³³ Ibid.

¹³⁴ DOE, *Critical Materials Rare Earths Supply Chain*, 4.

¹³⁵ Ibid., 3-6.

DOE's actions will also stimulate Call to Action 6 by growing the American critical minerals workforce.

Other steps the DOE took to support the Federal Strategy and improve understanding of REEs was through their forums. The Energy Efficiency and Renewable Energy and Office of Fossil Energy also hosted a *Critical Minerals Rare Earths Supply Chain Roundtable Workshop* at the Colorado School of Mines in Golden, CO in 2019 with multiple stakeholders, NTIB partners, and Japan.¹³⁶ The focus of the meeting was on up-to midstream REE supply chains. The forum allowed for the collaboration on solutions for separation and processing, a major gap in U.S. supply lines.

EO 13806: Strengthening the Manufacturing Base

On July 21, 2017, President Trump issued EO 13806 on *Assessing and Strengthening the Manufacturing and Defense Industrial Base and Supply Chain Resiliency of the U.S.*¹³⁷ The EO directs the Secretary of Defense to assess the manufacturing and DIB, assess risk, identify impacts, and propose mitigations. For the DoD, this assessment would come from INDPOL. This organization is the principal advisor to the Under Secretary of Defense for Acquisition and Sustainment. INDPOL promises the “robust, secure, resilient, and innovative industrial capabilities upon which

¹³⁶ DOE, *Critical Materials Rare Earths Supply Chain*, 4.

¹³⁷ Office of the Under Secretary of Defense for Acquisition and Sustainment, and Office of the Deputy Assistant Secretary of Defense for Industrial Policy (DOD), *Industrial Capabilities: Annual Report to Congress Fiscal Year 2018*, U.S. Department of Defense, May 2019, <https://www.businessdefense.gov/Portals/51/Documents/Resources/2018 AIC RTC 05-23-2019>, 29.

the DoD can rely to fulfill current and future warfighter requirements in an era of great power competition.”¹³⁸

DoD: INDPOL

INDPOL has several programs in place to protect and ensure DoD interests regarding economic issues relevant to national security. Although all programs depicted below are essential to national security, there are three programs this paper will focus on concerning stimulating the economy for REE interest. They are the Industrial Base Analysis and Sustainment (IBAS), Global Markets and Investments, and Defense Production Act (DPA) Title III (See Figure 7).



Figure 7. Organization of INDPOL

Source: Office of the Under Secretary of Defense for Acquisition and Sustainment, and Office of the Deputy Assistant Secretary of Defense for Industrial Policy, *Industrial Capabilities: Annual Report to Congress Fiscal Year 2018*, U.S. Department of Defense, May 2019, <https://www.businessdefense.gov/Portals/51/Documents/Resources/2018 AIC RTC 05-23-2019>, 29.

¹³⁸ DOD, *Industrial Capabilities: Annual Report to Congress Fiscal Year 2018*, 29.

In response to EO 13806, the IBAS uses Industrial Base Funds to solves domestic industrial capability gaps. They address critical issues in the industrial base for the DoD through prototype projects. They identify, attract, and cultivate NTIB compliant companies or entities through data calls or requests for contracts through their Cornerstone program. Using Other Transaction Authority money, prototype projects can be funded up to two-thirds of the cost of the whole project if the project demonstrates relevancy to the industrial base's ability to increase the effectiveness within the DoD. One disadvantage of this program is its long completion time because it relies on the normal government acquisition process which is slow. Contracts can be drafted quickly, but the projects themselves can take years to complete. Additionally, IBAS is also constrained by budget and FY deadlines, which limits the throughput of projects IBAS can grant. One recent project IBAS requested was a HREE separations facility, which was awarded to Texas Blue Line, a joint venture project with Lynas Corp.¹³⁹

The Global Markets and Investments Program manages CFIUS on behalf of the DoD. As mentioned earlier, this committee reviews foreign investment to protect U.S. interests. Global Markets and Investments conducts assessments of notified and non-notified transactions from foreign investors in the interest of national security. If transactions pose a risk, mitigation agreements similar to the sale of Magnequench are

¹³⁹ Office of the Secretary of Defense, PE: 0607210D8Z, *Industrial Base Assessment and Sustainment* (Washington, DC: U.S. Department of Defense, February 2018), Eric Hoover, Program Manager of the Industrial Base Analysis and Sustainment Program, telephone interview with author, May 1, 2020.

imposed, or the case may be presented to the President where he or she can prohibit the transaction.

The DPA Title III program has an excellent opportunity to stimulate growth in the REE industry. It promotes affordable and timely manufacturing capacities in order to be able to secure domestic industrial supplies quickly for national defense and homeland security under the 1950 DPA. The program has special provisions to secure projects faster than the average government acquisition process and is comparable to mainstream company timelines. A new legislation proposal would allow up to “U.S. \$1.75 billion on REE in munitions and missiles and U.S. \$350 million for microelectronics. It would also eliminate caps when it comes to hypersonic weapons.”¹⁴⁰ DPA III has a larger budget than IBAS, and their allotted funds do not expire at the end of the FY.

The prime way the program acquires manufacturing capabilities is through the Funding Opportunity Announcements (FOAs). The program makes announcements to the public, and companies respond with proposals explaining the reasons why they should receive government funding. Recently, the President issued five Presidential Determinations expanding DPA Title III authorities. The Presidential Determinations included LREE, HREE, rare earth metals and alloys, sintered NdFeB permanent magnets, and SmCo permanent magnets.¹⁴¹ Consequently, two recent FOAs included a “call” or

¹⁴⁰ Joe Gould, “Pentagon legislation aims to end dependence on China for rare earth minerals,” *Defense News*, 21 May 2020, <https://www.defensenews.com/congress/2020/05/18/pentagon-legislation-aims-to-end-dependence-on-china-for-rare-earth-minerals/>.

¹⁴¹ Business Defense, “Defense Production Act Title III Presidential Determinations to Strengthen the Domestic Industrial Base and Supply Chain for Rare

request for a REE separations facility and NdFeB magnet production capability in December 2019. Redundancy in contracts within the DoD and outside the organization is avoided through the Joint Industrial Base Working Group. This weekly meeting with DoD members from INDOL and other government agencies collaborate across multiple organizations, collaborate on DIB issues, and stay abreast of market trends.¹⁴²

EO 13807: Environmental Review and Permitting
Process for Infrastructure Projects

President Trump also issued EO 13807, *Establishing Discipline and Accountability in the Environmental Review and Permitting Process for Infrastructure Projects*, which directs Federal agencies to use existing coordination provisions to expedite the environmental review requirements for priority infrastructure projects.¹⁴³ The Federal Permitting Improvement Steering Council added non-energy mining as an infrastructure covered under Title 41 of the Fixing America's Surface Transportation

Earth Elements,” July 23, 2019, <https://www.businessdefense.gov/News/News-Display/Article/1913110/defense-production-act-title-iii-presidential-determinations-to-strengthen-the/>.

¹⁴² DoD, *Industrial Capabilities: Annual Report to Congress Fiscal Year 2018*, 14.

¹⁴³ U.S. President, Executive Order 13807, “Establishing Discipline and Accountability in the Environmental Review and Permitting Process for Infrastructure Projects.” August 15, 2017. accessed April 26, 2020, <https://www.energy.gov/nepa/downloads/eo-13807-establishing-discipline-and-accountability-environmental-review-and>.

(FAST) Act, qualifying mines as High Priority Infrastructure Projects (HPIP).¹⁴⁴ To date, the governors of Texas and Alaska requested Round Top Mine and Bokan Mountain, respectively, to be expedited for approval for “High Priority Infrastructure Projects” under the Trump Administration’s EOs for Environmental Reviews.¹⁴⁵

Other laws enacted to help increase domestic sources of production for critical materials are the Buy American Act, the Berry Amendment, the Specialty Metals clause, and section 871 of the John S. McCain National Defense Authorization Act for FY 2019. The law prohibits DoD appropriation of particular kinds of tungsten and rare earth magnets from the PRC, Russia, North Korea, and Iran. The law ensures that certain rare earth metals and alloys come from qualifying countries including NATO countries and Japan. These laws feed into the DFARS standard, protecting national security.¹⁴⁶ These restrictions support reliable sources of supply while protecting U.S. defense programs

¹⁴⁴ Federal Infrastructure Permitting Dashboard, “New Sectors for FAST-41,” Federal Infrastructure Projects, accessed January 15, 2020, <https://cms8.permits.performance.gov/about/news/new-sectors-fast-41>

¹⁴⁵ Michael J. Dunleavy, “Governor of Alaska’s Approval for High Priority Infrastructure Project,” Alaska, August 9, 2019; Mary Neumayer, “Letter to Governor Greg Abbott regarding HPIP,” March 23, 2018.

¹⁴⁶ The DoD is prohibited to purchase NdFeB and SmCo magnets from China, Russia, North Korea, and Iran. In the case of magnets, the prohibition is tied to where the alloy is first melted and the subsequent sintering operation takes place. This rule does not apply when magnets are not acquired at a reasonable price within the required timeframe. See U.S. Department of Defense (DOD), Defense Acquisition Regulations System, “Defense Federal Acquisition Regulation Supplement: Restriction on the Acquisition of Certain Magnets and Tungsten (DFARS Case 2018-D054),” *Federal Register* 84, no. 83 (April 30, 2020): 18156-18157, <https://www.federalregister.gov/documents/2019/04/30/2019-08485/defense-federal-acquisition-regulation-supplement-restriction-on-the-acquisition-of-certain-magnets>.

from less reliable strategic material supply chains. It is important to note, however, that the REOs used to make downstream products often originate from China.

Chapter Conclusion

The loss of the U.S.' longstanding worldwide leadership and expertise in REE to China left the U.S. in a vulnerable position. REE companies rely heavily upon China for their REE provisions from upstream to downstream operations. At any point, China could limit or stop the export of REEs to the U.S. which would cripple the DIB and slow American innovation.

The global demand for REOs is projected to increase from U.S. \$3.7 billion in 2018 to U.S. \$15.8 billion by 2030.¹⁴⁷ The rare earth supply chain is complex and heavily influenced by China. Multiple options for reducing and eventually ending U.S. dependence on China for REEs have been explored by Congress and other governmental agencies. This study is doing the same. The next chapter outlines its methodology for identifying opportunities and determining feasible short-term and long-term solutions to this challenge of developing a diversified and secure REE supply chain

¹⁴⁷ Brian Sullivan, "Rare earth minerals are a big element in the China trade fight," *CNBC*, October 17, 2019, <https://www.cnbc.com/video/2019/10/17/rare-earth-minerals-are-a-big-element-in-the-china-trade-fight.html>.

CHAPTER 3

RESEARCH METHODOLOGY

Introduction

The purpose of this study is to explore possible viable options to end U.S.’ dependency on Chinese production and refinement of REEs. The vulnerabilities in REE supply chains highlighted in Chapter Two have significant downstream impacts on the DIB, endangering U.S. national security. In order to help resolve these issues, the study focuses on lowered tiered material solutions through multiple case studies on advanced mining projects and separation plants in the U.S., Canada, and Australia through qualitative analysis. Separation facilities were included in the study to avoid dependence on China for the refinement of REEs, which is the lynchpin of the U.S. REE supply chain currently.

Qualitative Approach

The study uses the multiple case study model to explore and answer the research question: can the U.S. ensure reliable resources of REEs independent of China? The advantages of the multiple case study model are that they highlight similarities between companies and provide insight into the effectiveness of U.S. government policies to end dependence on China for REEs.¹⁴⁸ The disadvantage of the case study approach is that it cannot be generalized for other strategic studies. In order to mitigate the disadvantages,

¹⁴⁸ John W. Creswell, *Qualitative Inquiry and Research Design: Choosing among Five Approaches* (Thousand Oaks, CA: SAGE, 2007) 74-75.

multiple cases show different perspectives to draw conclusions and answer the research question. Data collected are from journal articles, newspaper articles, books, interviews, documents, government records and documents. The data was collected from October 2019 to May 2020 to ensure relevancy.

This study offers short- and long-term solutions for REE options for lower-tier material solutions, explicitly mining and separations facilities. Companies identified are narrowed down through deductive means. First, to offer short-term solutions to the research question, active mines compliant with NTIB standards were identified. The mines are Mount Weld in Australia and Mountain Pass in California. Second, long-term solutions were identified by using the 2017 USGS advanced REE exploration projects in North America and selected companies that: (1) met the NTIB standard; (2) showed the mine had economic viability through a PEA or PFS; and (3) had plans for a NTIB compliant separations facility. The mines identified were Bear Lodge Mountain, Bokan Mountain, Round Top Mountain, and Thor Lake. All other locations identified in the study either did not have a company exploring the deposit with an associated PEA/PFS or lacked a separations facility incorporated into their plan.

There are some considerations and concerns with information gathered for long-term solutions. PEAs, a standardized technical report, use inferred resources to answer the question of how the deposit can be exploited to maximize its economic returns. PEA typically is the first step to secure financing for mining operations and shows that there is a reasonable expectation of the profitability of the mine. To mitigate concerns over the accuracy of the technical reports, the study only included reports that were National Instrument 43-101 compliant (Standards of Disclosure for Mineral Projects). This means

that the technical reports were reviewed for accuracy and completeness by qualified geoscientists and engineers with at least five years of experience in mineral exploration, good standing with associations in their field of expertise, and favorable peer reviews of their work. Each PEA had at least three to five field experts reviewing the data within each technical report.

Evaluation

The evaluation criterion in Table 3 will apply to each case study listed in the previous section. The six questions listed will determine if the U.S. can ensure reliable resources of REEs independent of China. The analysis of each company will be either negative, neutral, or positive. Benchmarks are outlined in detail in the table below to clearly between negative, neutral, and positive clearly.

There are six main questions that the research will attempt to answer. (1) Does the mining and separation facility fit the timeline of implementation before 2035? The year 2035 coincides with the JOE. (2) Does the mine exist outside of China? This question ensures the mine is not physically located with U.S. competitors. (3) Does the separation facility exist outside of China? This also ensures REE concentrations are refined outside of China. (4) Is the refined REE heavy? This question ensures a healthy mix of light and heavy REEs for a diverse supply stream. (5) Does the production rate cover the 2019 consumption rate? This question addresses if the production rate could provide U.S. consumption rates for commercial and military use. The consumption rate in 2019 was

13,000 metric tons..¹⁴⁹ (6) Is there foreign investment from China? To avoid a majority takeover of a NTIB company like Magnequench, this explores if the company has Chinese investors. The results of the data will help identify if each company could assist in diversifying the REE supply chain independent of China.

Table 3. Evaluation Criteria			
Question	Negative	Neutral	Positive
1) Does the mining and separations facility fit the timeline of implementation before 2035?	The model does not fit the timeline or lacks enough evidence to evaluate.	The model could fit the timeline with caveats.	The model does fit the timeline.
2) Does the mine exist outside of China?	The mine exists inside of China or will be built in China.	The mine does not exist within the NTIB or will not be built in China.	The mine does not exist inside of China and is NTIB compliant.
3) Does the separations facility exist outside of China?	The separation facility will be built in China or the facility has yet to run its pilot program.	The separations facility does have a successful pilot program and will not be built in China.	The separation facility does not exist inside of China and is NTIB compliant.
4) Is the refined REE heavy?	The refined REE is not heavy or light.	The refined REE produced will be light.	The refined REE produced will be mostly heavy.
5) Does the production rate cover the 2019 consumption rate?	The production rate does not cover the 2019 consumption rate, or no mining operations are taking place.	The production rate could cover the 2019 consumption rate with other NTIB compliant mines.	The production rate does cover the 2019 consumption rate.
6) Is there foreign investment from China?	The company does have foreign investment(s) from China.	The company does have foreign investors from China, but they do not hold a majority stake in the company.	The company does not have foreign investment from China.

Source: Created by author.

¹⁴⁹ See USGS, *Mineral Commodities Summary 2020*, 131-132.

Research Methodology

The following is the step-by-step approach for the research in this thesis:

Step 1: The literature review was the first step to the research design in order to help answer the question, “can the U.S. ensure reliable resources of REEs independent of China?” This literature review was presented in Chapter Two.

Step 2: The second step in the research design was to answer secondary research questions. This was also done in Chapter Two.

Step 3: The third step in the research design applied the evaluation criterion to answer the primary research question.

Step 4: Finally, drawing conclusions and making recommendations was the last step of the research design. The results were presented in a descriptive narrative rather than a scientific report. This allows readers to understand the challenges of diversifying the REE value supply chain.

Threats to Validity and Reliability

The research design outlined above is a logical set of statements executed with trustworthiness, credibility, and data dependability. Validity is typically seen as a strength in qualitative studies, but it is used to determine if the data is accurate from the viewpoint of the researcher.¹⁵⁰ To ensure internal validity, the study employs triangulation of data, member checking, and clarification of researcher bias (see Chapter One). The primary strategy utilized in this project to ensure external validity will be through detailed

¹⁵⁰ John W. Creswell, *Research Design* (Thousand Oaks, CA: SAGE, 2003), 195-196.

descriptions to allow for reliability and transferability. First, the study covers a detailed account of the focus of the study. Then, triangulation strengthens the reliability and internal validity of the study. In order to accomplish this, the study uses primary source documents from selected companies, including press releases, PEA, PFS, and other publications. The information is then triangulated with reports from the USGS, CRS, and the DOE to ensure accuracy. Finally, the collection and analysis is reported in detail to provide a clear and accurate picture of the methods used.

Chapter Conclusion

In the next chapter, opportunities presented will determine if the U.S. can ensure the diversification of the REE supply chain. The results will avoid economic levers induced by China to halt exportation of REEs. The literature review and application of evaluation criterion to multiple case studies will answer primary and secondary research questions. The goal of this research methodology is to concisely answer the primary research question given the threats to validity, biases, limitations, and delimitations.

CHAPTER 4

DATA PRESENTATION AND ANALYSIS

Introduction

In this chapter the theoretical framework is applied to several case studies. Options outlined will inform U.S. policymakers involved with DIB with ways to support national security objectives and the DOC's Federal Strategy. Then the evaluation criterion will be applied to assess the companies and answer the research question: "Can the U.S. ensure reliable resources of REE independent of China?" As discussed in Chapter One, the study will only focus on advanced mining projects with plans for a separation facility compliant with NTIB standards.

The goal or end state must be identified to consider possible lines of effort. The end state is to secure a NTIB compliant REE supply chain independent of China. Then, the study explores the upstream and midstream options and determines if the supply chain is independent of China. Since China dominates all aspects of processing, the study will explore viable downstream solutions. Finally, the findings will be covered in Chapter Five.

Upstream and Midstream: Active Mines

Using information gathered from USGS, there are two mines compliant with the NTIB. They are Mount Weld, Australia owned by Lynas Corporation, and Mountain Pass, owned by MP Materials. Mount Weld will be evaluated first (see Table 4), followed by Mountain Pass (see Table 5).

Mount Weld

Table 4. Evaluation Criteria for Mount Weld, Australia			
Question	Negative	Neutral	Positive
1) Does the model fit the timeline of implementation before 2035?	Positive: The model does fit the timeline.		
2) Does the mine exist outside of China?	Positive: The mine does not exist inside of China and is NTIB compliant.		
3) Does the separations facility exist outside of China?	Neutral: The separations facility does not exist within the NTIB but the separations facility is not in China.		
4) Is the refined REE heavy?	Neutral: The refined REE is mostly light. The company does separate SEG heavies.		
5) Does the production rate cover the 2019 consumption rate?	Neutral: The production rate could cover the 2019 consumption rate but it does not satisfy all REE needs.		
6) Is there foreign investment from China?	Positive: The company does not have foreign investment from China.		

Source: Created by author.

The Mount Weld mine does fit the timeline of 2035 because it is currently active and produced 19,737 metric tons of REE in 2019.¹⁵¹ Their separation facility is in Malaysia, which is not a NTIB country, but the plant is also not in China. The main REOs the company, Lynas, produces are neodymium, praseodymium, cerium, lanthanum cerium, and SEG (samarium, europium, gadolinium). The oxides listed are mostly LREEs. However, the company just received a letter of intent from the DoD to receive funding for a HREE separation facility in Texas as a joint venture project with Texas

¹⁵¹ Lynas Corporation Ltd., *2019 Annual Report* (Sydney, Australia, 2019), II.

Blue Line. With government funding, Lynas Corporation will have a NTIB compliant “mine to separation” operation. The company also does not have foreign investments from China. Lastly, the current production rate does not meet the U.S. consumption rate.

Mountain Pass

Table 5. Evaluation Criteria for Mountain Pass, CA			
Question	Negative	Neutral	Positive
1) Does the model fit the timeline of implementation before 2035?	Positive: The model does fit the timeline.		
2) Does the mine exist outside of China?	Positive: The mine does not exist inside of China and is NTIB compliant.		
3) Does the separations facility exist outside of China?	Neutral: The separations facility does exist inside the U.S. but is not operational.		
4) Is the refined REE heavy?	Neutral: The refined REE is mostly light. The company will separate SEG heavies in the future.		
5) Does the production rate cover the 2019 consumption rate?	Neutral: The production rate could cover the 2019 consumption rate but it does not satisfy all REE needs.		
6) Is there foreign investment from China?	Neutral: The company does have foreign investors from China but they do not hold a majority of the shares.		

Source: Created by author.

Mountain Pass could supply U.S. needs in LREE materials based on their 2019 mining production rates, which was 26,000 metric tons. REE concentrates are shipped to China for purification and separation, covered in chapter Two. Currently, MP Materials does not have a separations facility but plans to recommission the existing refinery at Mountain Pass. By the end of 2020, Mountain Pass will “produce high-purity separated neodymium and praseodymium oxide, lanthanum and cerium oxides and carbonates, and

“heavy” rare earth concentrates.”¹⁵² One neutral aspect of the company is that 10 percent of the Mountain Pass venture is owned by a Chinese firm Leshan Shenghe Rare Earth Co.¹⁵³ The benchmark is determined as neutral because this foreign company does not have a controlling voting share of the company. However, this firm may buy more shares in the future. This is an area of concern, and if the Chinese firm seeks a majority stake in the company, CFIUS should intervene.

MP Materials is intent on preserving and maintaining clean energy. The company uses a dry-stacked tailings process to eliminate groundwater contamination and recirculates 90 percent of its processed water. Their upstream process of milling and beneficiation consumes less freshwater than normal mining operations. Their closed-loop system takes waste solution from separated REE, and it is recycled on-site to create a chemical reagent for processing.¹⁵⁴ Remembering Molycorp’s experiences with the EPA, the company took tremendous steps to comply with the strictest environmental regulations. Based on the company’s environmentally friendly standards, MP Materials will be able to operate the mine until its expected closure.

¹⁵² MP Materials, “What are Rare Earths?” accessed April 14, 2020, <https://mpmaterials.com/products/>.

¹⁵³ Bloomberg News, “The Californian Rare Earths Mine Caught Between Trump and China,” *Bloomberg*, September 28, 2018, <https://www.bloomberg.com/news/articles/2018-09-27/the-californian-rare-earths-mine-caught-between-trump-and-china?sref=38hIy4be>.

¹⁵⁴ See MP Materials, “Why we are different,” accessed March 12, 2020, <https://mpmaterials.com/sustainability/>.

Upstream and Midstream: Advanced REE Exploration Projects

This section explores advanced REE exploration projects with separation plants to offer long-term solutions for U.S. policymakers. Bear Lodge, Bokan, Round Top Mountain, and Thor Lake will be evaluated according to the criteria. Then further exploration will highlight similarities and areas where government policy assisted in the development of these projects. Due to insufficient information, all three mines have a negative benchmark for criteria 1. Although some mines have estimated timeframes, there are many factors that can derail mining timelines including long lead times, negative environmental studies, and a lengthy permit approval process. The advantages are each company's intent for a domestic supply chain and their sole ownership of the respective mountains.

Table 6. Evaluation Criteria for Bear Lodge, Bokan and Round Top Mountain			
Question	Negative	Neutral	Positive
1) Does the model fit the timeline of implementation before 2035?	Negative: There is insufficient information to make an evaluation.		
2) Does the mine exist outside of China?	Positive: The mine will not exist inside of China and will be NTIB compliant.		
3) Does the separations facility exist outside of China?	Neutral: The separations facility does have a successful pilot program and will not be built in China.		
4) Is the refined REE heavy?	Positive: The refined REE produced will be mostly heavy.		
5) Does the production rate cover the 2019 consumption rate?	Negative: No mining operations are taking place.		
6) Is there foreign investment from China?	Positive: The company is does not have foreign investment from China.		

Source: Created by author.

Bear Lodge

Rare Element Resources, owner of Bear Lodge Mountains, conducted a detailed exploration of the property between 2004 and 2013, using a variety of geological, geochemical, and geophysical methods. In October 2014, the company completed a positive feasibility study on Bear Lodge and estimated a 45-year mine life. The USGS stated that it has one of the largest deposits of disseminated REE in North America. Its high ore content is detailed in their 2014 feasibility study.¹⁵⁵ Mineral deposits at Bear Lodge share similarities with the Mountain Pass and Mount Weld deposits. The Bear Lodge mine is expected to produce HREE and LREEs, including the neodymium, dysprosium, europium, praseodymium, terbium, and yttrium. These raw materials are expected to be used for high-strength, permanent magnets. The company does not have a time frame for when the mine will be operational.

Rare Element Resources has been working with Umwelt-und Ingenieurtechnik GmbH Dresden, a German company and affiliate of Synchron, for hydrometallurgical separation technology since February of 2019.¹⁵⁶ Umwelt-und Ingenieurtechnik GmbH Dresden operated the pilot plant designed to produce several products, including a high-

¹⁵⁵ Peter S. Dahlberg, “Bear Lodge Project Canadian NI 43-101 Pre-Feasibility Study Report on the Reserves and Development of the Bull Hill Mine, Wyoming.” Report for Rare Element Resources, Roche Engineering Inc., Sandy, UT, October 9, 2014.

¹⁵⁶ Rare Element Resources, “Rare Element Resources Reports Successful Confirmation and Enhancement of its Proprietary Separation Technology,” February 12, 2019, <http://www.rareelementresources.com/investor-information/news-releases/2019/02/12/rare-element-resources-reports-successful-confirmation-and-enhancement-of-its-proprietary-separation-technology#.XtUIUMBOI4E>.

purity neodymium praseodymium oxide, lanthanum oxide, and a mixed mid and heavy rare earth concentrate. The pilot program was announced as a success in February 2020. Although the company Umwelt-und Ingenieurtechnik GmbH Dresden is not a member of NTIB, Rare Element Resources plans to open their Hydrometallurgical Plant in Upton, WY.¹⁵⁷

Bokan Mountain

Bokan Mountain is another potential REE mine owned by the Canadian company, Ucore Rare Metals. The company is looking to develop a non-Chinese rare earth supply stream through their strategic M³ plan: mine to metal to market.¹⁵⁸ Ucore plans to “mine” ores from Bokan Mountain to create a mixed beneficiated concentrate. Then, separate concentrates into oxides and convert oxides into “metals” and alloys where they can be used for permanent magnets or other end-item products for the “market”. The mineral ore at Bokan Mountain is characterized by a high proportion of HREEs, especially europium to lutetium and yttrium.¹⁵⁹ The company understands the importance of HREEs and is enthusiastic about “HREE independence” for the U.S.¹⁶⁰

¹⁵⁷ Rare Element Resources, “Bear Lodge Project,” accessed April 5, 2020, <http://www.rareelementresources.com/bear-lodge-project/proposed-operations#.Xs25VMBOI4E>.

¹⁵⁸ Ucore Rare Metals Inc., “M³ Plan of Action,” Bedford, Canada, September 27, 2020.

¹⁵⁹ Tetra Tech, “Preliminary Economic Assessment on The Bokan Mountain Rare Earth.” PEA for Ucore Rare Metals, Pasadena, CA, January 10, 2013, 13-20.

¹⁶⁰ Pat Ryan, “M³ Plan of Action - Mine to Metal to Market - Pat Ryan, Chairman of the Board,” video, October 16, 2019, <https://www.youtube.com/>

Bokan Mountain will be an underground mining operation producing 1,500 tons per day. Additionally, the mountain's location on the Pacific Ocean provides a logistical advantage to ship REOs to consumers. The company hopes to complete all engineering and permitting by 2022.¹⁶¹ Another advantage is its state funding. On March 31, 2014, the Alaska State Legislature granted an investment of up to U.S. \$145 Million in the Bokan project at the discretion of the Alaska Import Development and Export Agency. This would cover two-thirds of their capital costs for establishing the mine. The Governor of Alaska also submitted a HPIP letter to the Council of Environmental Quality. The determination of that letter has yet to be announced. The company has published an aggressive 30-month plan to establish their mine once permitting is approved.¹⁶² The disadvantages to the potential mine is the impact of thorium and uranium on the environment.

Ucore also plans to build a separation plant. According to the CEO of Ucore, DPA Title III provided a unique opportunity in July 2019, one that would open avenues of swift development for their separation facility, the Alaska Strategic Metals Complex.¹⁶³ Ucore recently bought 100 percent of the shares of Innovations Metals

watch?v=dP08WnjGkNg&fbclid=IwAR1rxFk_fOh5jKe5x0R3F0KHtiREE0OeF46tOsPTeSV0nISxUXZpuconids.

¹⁶¹ Ucore Rare Metals Inc., "M³ Plan of Action."

¹⁶² According to the DOE, the mine is expected to be operational in three to four years. See DOE, *Critical Materials Rare Earths Supply Chain*, 6.

¹⁶³ Ryan, "M³ Plan of Action."

Corporation, a private corporation based in Toronto known for its separation technology developed with DoD funding called RapidSX. This process is an accelerated solvent-extraction-based separation technology using reducing processing time.¹⁶⁴ Their pilot-scale operation is located in Mississauga, Ontario, is capable of separating up to 5 to 10 metric tons of metals per month.¹⁶⁵ Ucore intends to use Innovation Metal's RapidSX separation technology to purify REOs for their production line. The company has outlined a 12-month plan for the facility once financing and resources are secured. Once operational, Bokan Mountain will produce heavy REOs independent of China.

Round Top

Round Top recently has drawn a lot of attention from investors due to its return on investment projections. Based on their PEA, Round Top Mountain contains five out of six light rare earths, ten out of eleven heavy rare earths, and all five permanent magnet materials.¹⁶⁶ Feasibility work and permitting for the mine continue this year, with construction slated to begin in late 2021. The advantages of the project include low capital and operating costs as well as streamlined permitting. All investors involved are

¹⁶⁴ Reported as U.S. \$1.2 million in funding from the Army Research Lab. Other press releases claim the DoD funded U.S. \$1.8 million for their separations research. See Innovation Metals Corporation, "Rare Earth Separation," accessed April 12, 2020, <http://www.innovationmetals.com/rare-earth-separation/>.

¹⁶⁵ Innovation Metals Corporation, "The RapidSX Process," accessed April 14, 2020, <http://www.innovationmetals.com/the-rapidsx-process>.

¹⁶⁶ Gustavon Associates, "NI 43-101 Preliminary Economic Assessment," Sierra Blanca, TX, 2019, 81-82.

part of the NTIB list, promoting transparency. The governor of Texas submitted a HPIP on behalf of Round Top and the Council of Environmental Quality accepted the letter. Final approval is still pending with the Federal Permitting Improvement Steering Council. The disadvantages are that adjacent rocks may contain traces of radioactive elements, and its disposal may be costly. The company does not know if residual material after processing will be classified as treated rock or as contaminated mineral material.¹⁶⁷ Currently, there are no estimates on its mineral reserves; however, their PEA estimates REO mining rates of 3,325 tons per year. The company anticipates commercial production at the mine to begin in 2023.¹⁶⁸

Although the mine has yet to be constructed, the project invested significant research and testing on later phases of production. The Round Top Project is a unique one due to opening its HREE and LREE processing facility before its mining efforts. Texas Mineral Resources Corporation, with their joint venture Australian partner, USA Rare Earths, successfully separated three rare earth minerals during their pilot program using Defense Logistics Agency funding.¹⁶⁹ The company tested their Continuous Ion

¹⁶⁷ Gustavon Associates, “NI 43-101 Preliminary Economic Assessment,” 97.

¹⁶⁸ Jim Vinoski, “The U.S. Needs China For Rare Earth Minerals? Not For Long, Thanks To This Mountain,” *Forbes*, April 7, 2020, <https://www.forbes.com/sites/jimvinoski/2020/04/07/the-us-needs-china-for-rare-earth-minerals-not-for-long-thanks-to-this-mountain/#3a1bb39528b9>.

¹⁶⁹ USA Rare Earth, “USA Rare Earth and Texas Mineral Resources Corp Announce Opening of First Heavy and Light Rare Earths Processing Facility Outside of China,” *PR Newswire*, December 16, 2019, <https://www.prnewswire.com/news-releases/usa-rare-earth-and-texas-mineral-resources-corp-announce-opening-of-first-heavy-and-light-rare-earths-processing-facility-outside-of-china-300975088.html>.

Exchange and Continuous Ion Chromatography refinement process to produce a 99.99 percent high purity REO. The Continuous Ion Exchange and Continuous Ion Chromatography uses positive and negative ions to extract and purify desired compounds or produce REOs. USA Rare Earth has announced that its Wheat Ridge, CO, processing plant would be ready for operations by the second quarter of 2020 and that later full-scale continuous process operation on the Round Top site would begin.¹⁷⁰ The CEO of USA Rare Earth stated:

Our Colorado pilot plant will be the first processing facility outside of China with the ability to separate the full range of rare earths – Lights, Mids and Heavies. Our Wheat Ridge pilot plant is the second piece of a 100% U.S.-based rare earth oxide supply chain, drawing on feedstock from our Round Top heavy rare earth and critical minerals deposit in southwest Texas. Taken together, Round Top and our pilot plant constitute essential links in restoring a domestic U.S. rare earth supply chain, extracting rare earths and processing them into individual REE oxides – without the material ever leaving the U.S., thereby alleviating the current dependence on China for both raw materials and mineral processing.¹⁷¹

Additionally, the company's method of REE extraction and separation will remain environmentally friendly due to the ion exchange-ion chromatographic method.

¹⁷⁰ USA Rare Earth, "USA Rare Earth and Texas Mineral Resources Corp Announce Opening of First Heavy and Light Rare Earths Processing Facility Outside of China."

¹⁷¹ Ibid.

Thor Lake (Nechalacho)

Table 7. Evaluation Criteria for Thor Lake			
Question	Negative	Neutral	Positive
1) Does the model fit the timeline of implementation before 2035?	Negative: There is insufficient information to make an evaluation.		
2) Does the mine exist outside of China?	Positive: The mine will not exist inside of China and will be NTIB compliant.		
3) Does the separations facility exist outside of China?	Negative: The facility has yet to run its pilot program.		
4) Is the refined REE heavy?	Positive: The refined REE produced will be mostly heavy.		
5) Does the production rate cover the 2019 consumption rate?	Negative: No mining operations are taking place.		
6) Is there foreign investment from China?	Positive: The company is does not have foreign investment from China.		

Source: Created by author.

Thor Lake, also known as Nechalacho, is one exploration company interested in rare earths. The company is better known for its mining ventures in lithium but the CEO and geologist, Don Bubar, recognized the growing importance of REEs. Thor Lake has significant reserves of REEs for a mine life of 20 years..¹⁷² In 2013, the company conducted a feasibility assessment of the Thor Lake project and found deposits of high-grade neodymium praseodymium, and dysprosium resources. The company plans to produce neodymium praseodymium rich products on a smaller scale using low-cost ore-

¹⁷² Avalon Rare Metals, “Avalon Announces Results of Positive Feasibility Study for the Nechalacho Rare Earth Elements Project.”

sorting technology. Bubar believes “operations [should] be established at a small scale without large capital requirement. Prove you can make a product acceptable in the market and [have] outlets for refining. Once you’ve done that, then look at how you can scale up the business.”¹⁷³

In a 2013 newsletter, the company announced their plans to set up a refinery in Geismar, LA. The feasibility study estimates the annual production from the refinery will average approximately 7,000 metric tons per year.¹⁷⁴ The refinery has two plants: a leaching plant and a separation plant. Waste naturally accumulates from the leaching and separation. The waste will be stored in engineered waste impoundment cells on the Geismar property.

Midstream Analysis: Processing

There are other midstream solutions to consider for processing. Eutectix, mentioned in Chapter Two, is involved with processing rare earth alloys in the U.S. However, the company is 100 percent reliant on Chinese rare earth materials to make magnets and alloys.¹⁷⁵ It is difficult for midstream companies to diversify their supply stream independent of China.

¹⁷³ Don Bubar, “Don Bubar on the renewed concern about the security of supply of rare earths in the global markets,” interview by Tracy Weslosky, *InvestorIntel*, July 16, 2019, https://www.youtube.com/watch?v=O_XkB-H020g

¹⁷⁴ Avalon Rare Metals, “Avalon Announces Results of Positive Feasibility Study for the Nechalacho Rare Earth Elements Project.”

¹⁷⁵ Jason Clune, Chief Marketing officer of Eutectix, email with author, May 12, 2020.

Avalon is exploring the option to recover rare earths from coal wastes at their closed mine site in southern Illinois. In September 2016, the Office of Fossil Energy of the DOE issued a U.S. \$23.75 million Financial Assistance FOA titled: Production of Salable REE from Domestic U.S. Coal and Coal By-Products.¹⁷⁶ In 2019, the DOE proposed a Critical Materials Initiative within the Fossil Energy R&D program under the Advanced Coal Energy Systems program to examine new technologies to recover REEs from coal and coal byproducts.¹⁷⁷ Based on previous studies, the company hopes for a near term potential solution to recover rare earths and byproducts dissolved in acidic wastewater and lime treatment precipitates at a low cost by utilizing an innovative new rare earth recovery technology.¹⁷⁸ Avalon is planning a small scale pilot plant in the second quarter of 2020 to test the process before building a larger scale plant later in 2020.

Downstream Analysis

Several companies are involved in the permanent magnet making business within the U.S. mentioned in Chapter Two. The Electron Energy Corporation, AZ Industries, and Arnold Magnetics produce permanent magnets on a smaller scale. However, each

¹⁷⁶ FedConnect, “Opportunity: DE-FOA-0001627 – NOI,” accessed May 2, 2020, <https://www.fedconnect.net/FedConnect/default.aspx?doc=DE-FOA-0001627&agency=DOE>.

¹⁷⁷ CRS, CRS Report R45810, 9-10.

¹⁷⁸ Avalon Advanced Materials Inc., “Developing the Supply Chain for the Clean Economy in Canada,” (PowerPoint Presentation, Toronto, Ontario, Canada, May 2020), http://avalonadvancedmaterials.com/_resources/presentations/Corporate_Presentation.pdf.

company is heavily reliant on China for rare earth materials unless customers request DFARS compliant magnets. This only ensures the alloy created for magnet making is produced outside of North Korea, China, Russia, or Iran. Meanwhile, the upstream materials to make the alloys originate from China, making it difficult to be independent of China's grip in the U.S. REE supply chain.

Part of the problem with downstream manufacturing is that the DoD purchases from system integrators.¹⁷⁹ This means the DoD purchases end-item systems like night vision goggles. Then, the company that manufactures night vision goggles is responsible for securing the supplies to build the system. In the event of a supply disruption, the manufacturing of the night vision goggle would be delayed or halted entirely. This would prevent combat units from having a technological edge over the enemy. Currently, there is no company that owns upstream to downstream operations within the NTIB.

Other companies are attempting to own upstream to downstream processes. For example, USA Rare Earth, associated with the Round Top project, announced the acquisition of the NdFeB permanent magnet production equipment formerly owned and operated by Hitachi Metals America, Ltd. in North Carolina.¹⁸⁰ Currently, the company has no domestic manufacturing capacity. However, the company will warehouse the

¹⁷⁹ Jack Lifton, "The U.S. Rare Earths Supply Chain Challenge - Part 4," interview by Tracy Weslosky, *InvestorIntel*, March 29, 2019, <https://www.youtube.com/watch?v=NGo20lpc9oM>.

¹⁸⁰ USA Rare Earth, "USA Rare Earth Acquires U.S. Rare Earth Permanent Magnet Manufacturing Capability," *Global Newswire*, April 7, 2020, <https://www.marketwatch.com/press-release/usa-rare-earth-acquires-us-rare-earth-permanent-magnet-manufacturing-capability-2020-04-07>.

equipment while they search for a suitable location for the new magnet production facility. The operation will produce 2,000 tons per year of rare earth magnets, which will fill approximately 17 percent of domestic demand.¹⁸¹ This is one company attempting to own the entire supply chain from upstream to downstream to secure America's interest.

Chapter Conclusion

REE mining and separation facility solutions under the NTIB are minimal. Government funding and EOs assisted multiple mining companies in gaining investor interest and capital for their rare earth projects. This chapter answered the primary research question using information from the literature review and aggregation of data. Each case study evaluated whether the U.S. could be independent of China's REE supply stream by 2035. The analysis discusses vulnerabilities in the supply chain and offers possible opportunities to secure an adequate supply chain. The case study highlights what areas require special attention to decrease vulnerabilities. Immediate solutions fitting the criteria for solving the REE supply chain problem is Mount Weld in Australia. The next chapter will answer the primary research question and discuss potential challenges in the future as well as some solutions. Lastly, the chapter covers recommendations for policy makers and recommendation for future research.

¹⁸¹ Vinoski, "The U.S. Needs China for Rare Earth Minerals?"

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

Introduction

A decade has passed since multiple government agencies and media sources highlighted rare earth supply chain vulnerabilities. Other countries, including the U.S., started mining REE concentrates, but the world's efforts so far cannot compete with China's production rates from upstream to downstream operations. China is still the leader of the rare earth industry. Globalization and the rapid changes in technology development have only propelled U.S. dependence on China for REEs. The U.S. will continue to rely heavily on China for rare earth materials in the near term. However, with the assistance of the government and the U.S. allied partners, the U.S. can have a REE supply chain independent from China in the future.

Findings

Based on the analysis conducted in Chapter Four, there are vulnerabilities throughout the supply chain from upstream to downstream operations. Upstream operations demonstrate viable quantities of REEs produced but mostly in LREEs. The NTIB currently lacks an active HREE producing mine. The demand for HREEs will increase once fossil-fueled cars are no longer desired by countries starting in 2025. For midstream operations, there are no separation plants able to separate both LREEs and HREEs in REOs on an industrial scale, which is key to producing permanent magnets in defense equipment. The only plant able to separate LREEs on a large scale is associated with Lynas' Malaysian Kuantun Plant. Most of the processing of REOs into metals and

alloys is done in China. However, the DFARS standard helps the DIB secure REE metals and alloys produced outside of China for permanent magnets. Overall, the U.S. is heavily reliant on China for separation, processing, and manufacturing of REE products.

Short-Term Options

Short-term options for securing a supply chain with the NTIB include upstream operations of Mount Weld and Mountain Pass. Mount Weld has a separation facility outside of China, but Mount Weld's facilities do not produce the highly sought after HREEs. Mountain Pass is another upstream option but, like Mount Weld, it only produces LREEs. Other disadvantages of Mountain Pass are its foreign investment and separation process in China. However, once the company's new separation facility is complete, this will alleviate dependence on China to produce REOs for the global market. These two LREE mines demonstrate the need for a wider base and diversification of upstream options.

For midstream and downstream short-term solutions, there are a handful of NTIB alloy and magnet making companies able to produce finished goods independent of China. However, most REE metal and alloy makers are dependent on REOs from China like Eutectix, which receives 100 percent of its raw materials from China. Magnet making companies can acquire non-Chinese alloy materials, however the product comes at a higher cost.

Long-Term Options

Long-term options for REEs are Bokan Mountain, Round Top Mountain, Bear Lodge Mountain, and Thor Lake. Each of these companies has a separation plant as a part

of the economic assessment or feasibility assessment. This would alleviate the need to send REE concentrates to China. Additionally, all the mines mentioned have plans to produce HREEs to meet future higher demands. If upstream processes are solidified in the NTIB, then midstream and downstream companies will have more options and opportunities to diversify supply chains and avoid a cutoff.

There are opportunities to separate of REE concentrates into REOs within the NTIB much sooner than previously anticipated. With a successful pilot in 2020, Round Top's separation facility could produce LREE and HREEs on an industrial scale. Once operational, this separation facility will assist in protecting the national interest by preventing mined ores from falling into foreign hands. This domestic capability will allow mines in the U.S. to diversify their options for separation.

An increase in upstream options can help midstream to downstream companies involved in REE metals, alloys, and manufacturing diversify their sources of supply. Eutectix has the equipment required to ramp up production and produce refined alloys on a larger scale. The permanent magnet company, Electron Energy Corporation, could have a transparent supply chain if NTIB countries provided its raw REE materials instead of China. Magnet producers could normalize the price of DFARS compliant products if materials were mined and produced locally. USA Rare Earth's recent purchase of Hitachi's equipment provides another opportunity for permanent magnets to be manufactured in the U.S. NTIB based REE companies are purchasing upstream to downstream processes in order to have a secure supply chain independent of China.

Challenges and Solutions

A recent article in *Foreign Policy* states:

Given China's state mandated dominance of niche rare-earth industry, it basically controls pricing and ensures that normal economic rules don't apply. That makes it hard to respond to China's current dominance by turning to market-based solutions, like urging mining companies to pour hundreds of millions of dollars into big upfront investments that could be rendered uneconomical with a single decision in Beijing.¹⁸²

There is a huge economic risk involved in REE mining operations. This rare earth industry imbalance will continue unless upstream mining projects are established in the NTIB. Midstream and downstream companies depend heavily on the diversification of supply from upstream companies. Therefore, the rare earth supply chain must be approached holistically, which means a multifront operation to solve upstream to downstream issues simultaneously. Several companies are attempting this endeavor but will need significant capital to sustain their projects from start to finish.

New mining companies have difficulty keeping operations afloat during the exploration and feasibility stages. One NTIB company, GeoMegA is recycling and repurposing REE materials from computers, smartphones, and magnets while it establishes their rare earth Montviel mining project in Ontario, Canada. The CEO of GeoMegA views the establishment of new mining projects to be a huge financial risk. The company entered the billion-dollar industry of recycling because it simply "makes

¹⁸² Keith Johnson and Robbie Gramer, "U.S. Falters in Bid to Replace Chinese Rare Earths," *Foreign Policy*, May 25, 2020, accessed May 26, 2020, <https://foreignpolicy.com/2020/05/25/china-trump-trade-supply-chain-rare-earth-minerals-mining-pandemic-tensions/>.

sense to close the loop”.¹⁸³ Plus, China practices recycling as well. He also made the point that recycling of REEs is not much different from beneficiation and separation of REEs in conventional mining processes. Other NTIB countries are finding unique ways to recycle permanent magnets. Professor Rex Harris from the University of Birmingham found when you “pass hydrogen over a rare earth magnet, the magnet expands and then turns into a powder.”¹⁸⁴ The powder loses its magnet properties and then can be recycled into a rare earth magnet again.

Another major challenge facing mining in the U.S. is permitting. According to *Defense News*, permitting a mine takes five times longer than it does in Canada and Australia.¹⁸⁵ The protracted permitting process often induces higher cost and increased risk before production even begins. Rare Element Resources, owner of Bear Lodge Mountain, knows this well as it is still waiting for the USFS to complete their EIS, which was submitted initially in January 2016.¹⁸⁶ The USFS has stated that National

¹⁸³ Kiril Mugerman, “Geomega Resources Pick Quebec as Site to Build Demonstration Plant,” interview by Steve Darling, *Proactive*, January 20, 2020, <https://www.youtube.com/watch?v=0mXAPDb9fKc>

¹⁸⁴ David Gregory-Kumar, “Recycling innovation makes gadgets a little bit greener,” *BBC News*, August 26, 2016, <https://www.bbc.com/news/uk-england-birmingham-37190469>.

¹⁸⁵ Jeffrey Green, “The collapse of American rare earth mining — and lessons learned,” *Defense News*, November 12, 2019, <https://www.defensenews.com/opinion/commentary/2019/11/12/the-collapse-of-american-rare-earth-mining-and-lessons-learned/>.

¹⁸⁶ Rare Element Resources, “Bear Lodge Project.”

Environmental Policy Regulations are currently under review.¹⁸⁷ Moreover, the USFS is only a small part of the permitting process. Approval must be gained by the EPA, the Bureau of Land Management, state Departments of Natural Resources, and state Utilities Commissions. For a mine to effectively maneuver through the complicated permit process, the companies must work closely with local, state, and federal governments. President Trump's EO 13807 aimed to assist in environmental reviews and permitting processes through the Council of Environmental Quality and by placing mines on the HPIPs. The HPIP recommendation letters give additional importance to mining projects crucial to national security. Only the Round Top project is approved as a HPIP, although final approval still remains with the Federal Permitting Improvement Steering Council. Therefore, Bokan Mountain and Round Top may see commercial production before 2035.

Another challenge for mining companies is the potential for radioactive waste. The environmental hazard of separating HREEs often produces unwanted radioactive byproducts. The process of disposing large amounts of radioactive waste will be both expensive and difficult to dispose of without government assistance. The Environmental Protection Agency can shut down mine operations like it did with Mountain Pass in 1998. In 2014, the National Rare Earth Cooperative Act was proposed as a way to advance the domestic refining of heavy REOs. The Act envisioned providing funding for the safe

¹⁸⁷ DOE, *Critical Materials Rare Earths Supply Chain*, 8.

storage of thorium for future uses using a cooperative ownership approach.¹⁸⁸

Unfortunately, this bill never made it through congress. In addition to thorium, a weak radioactive material, radium, and other highly radioactive intermediate products can accumulate during REE processing.¹⁸⁹ Because strict thorium regulations are expensive barriers to rare earth developers in the U.S.; the government should assist domestic mines through the safe disposal of thorium and fund additional research on alternative uses.

Another problem with the rare earth industry is the intellectual property and patents involved with processing and manufacturing. Intellectual property barriers become more of an issue during downstream operations particularly with the production of sintered NdFeB. Hitachi Metals currently owns these patent rights and often limits licensing their property to other companies.¹⁹⁰ Major manufacturers in China are currently licensed to manufacture and sell from Hitachi. However, the U.S. is not.¹⁹¹ If USA Rare Earths decides to manufacture NdFeB with their newly acquired equipment, the company will have to get permission from Hitachi to avoid a lawsuit.

Other options to secure supply chains include stockpiling. Maintaining and expanding the National Defense Stockpile would supply the DIB during national emergencies such as the COVID-19 crisis when supply chains are disrupted. According

¹⁸⁸ CRS, CRS Report R45810, 49.

¹⁸⁹ USGS, “Rare Earth Elements—Critical Resources for High Technology.”

¹⁹⁰ Secretary of Energy, *Critical Materials Strategy*. 56.

¹⁹¹ DOE, *Critical Materials Rare Earths Supply Chain*, 9.

to a report to Congress, the limited available resources within the National Defense Stockpile program will be financially unsustainable by 2026.¹⁹² The feasibility of purchasing large quantities of REEs is possible, but it does not guarantee the utility of the material. For example, if the U.S. stockpiles large amounts of rare earth alloys for the sole purpose of manufacturing permanent magnets, by the time the country might need such magnets, the magnets in storage could be obsolete due to the invention of a stronger permanent magnet. Stockpiling REEs can be part of a more extensive plan to ensure a secure REE supply chain, but stockpiling is not a long-term solution. The expected benefits of attaining REEs could outweigh the anticipated costs in the unfortunate event of an embargo. This plan of action is consistent with the current mood of the U.S. government and consistent with domestic concerns of interrupted supply chains for the DIB if a stockpile was non-existent. Stockpiling may not be what the Trump Administration had in mind when imagining clear supply chains; however, stockpiling does support the goals of national leaders.

Recommendations

Recommendations for Decision-makers

Actions by the Trump Administration and Congress from 2017 to 2019 have spurred new interest in securing REE supply chains. Additionally, the Federal Strategy provided a comprehension goal to solve the overdependence on China for critical minerals. Congress must not lose interest in the REE sector like it seemed to in 2013. The

¹⁹² DoD, *Annual Industrial Capabilities Report to Congress for 2018*, 68.

cobalt shortage of 1978, the 2010 Senkaku Island dispute and even the COVID-19 pandemic all demonstrate how a cessation in the supply of strategic materials can harm the U.S. Advocating for additional grants and funding will assist in bringing mining companies to commercial production. Multiple sources of funding are already in place, including IBAS, Defense Logistics Agency, DOE, DPA Title III, and DoD research labs. A cross-agency database to show transparency between agencies will avoid redundancy in contracts and projects from the same companies.

Reintroducing the METALS Act or *Materials Essential To American Leadership and Security Act* might also generate more interest in REEs.¹⁹³ The METALS Act was introduced in the House of Representatives in March 2017. The Act proposed funding five-year interest-free loans to companies engaged in the domestic production and processing of strategic and critical materials. The Act also supported the development of new technologies for more efficient processing of strategic and critical materials.¹⁹⁴ If enacted this new law would have provided a safety net for REE companies getting started. Most PEAs and PFS' from mining companies expected to settle their debts in 2.5 years if economically viable amounts are found. This law would further stimulate the economy plus produce multiple jobs, supporting the Federal Strategy Call to Action 6.

Another recommendation is to encourage states to fund mining projects in the interest of national security. Including non-energy mines on the HPIP list would be a

¹⁹³ See U.S. Congress. Materials Essential To American Leadership and Security Act. H. Res.1407.115th Cong., 1st Sess. H2017-18.

¹⁹⁴ CRS, CRS Report R45810, 52.

tremendous help to mining industries that are establishing operations. However, as of this writing, no mine has been officially accepted as a high priority status by the Federal Permitting Improvement Steering Council. Additionally, regarding the complicated process for obtaining permits, state and federal governments should proactively assist mining companies and other midstream and downstream REE companies in navigating the permit process, not just provide encouragement. Placing mining companies on the FAST-41 will advance REE mining companies for permitting in the interest of national security.

Finally, researchers and academia are in the early stages of discovery and development in substitutions and recycling. However, the DOE as well as other federal agencies are having difficulty demonstrating and comparing new technologies for commercial production. This includes testing discoveries on an industrial scale and highlights a problem with scalability. Working with NTIB universities and researchers, the U.S. government can help advance new discoveries by funding research. For example, the University of Birmingham's Magnetic Materials Group discovered a way to demagnetize and recycle permanent magnets.¹⁹⁵ GeoMegA, Urban Mining Company, and the DOE Innovations Hub are discovering and testing groundbreaking methods to repurpose and recycle REEs in everything from fluorescent lights to magnets. Moreover, the U.S.' recycling laws vary tremendously by state. Congress and U.S. policymakers

¹⁹⁵ Professors Rex Harris and Allan Walton worked with the Magnetic Materials Group and later patented the technology called Hydrogen Processing of Magnet Scrap in 2018 under their company, Hypromag. See Gregory-Kumar, "Recycling Innovation Makes Gadgets a Little Bit Greener," and Hypromag, "Rare Earth Magnetic Recycling," accessed May 20, 2020, <https://hypromag.com/>.

should look at the viability of mandatory recycling of REEs in the U.S. and the feasibility of employing recycling plant workers to help end-of-life REE products from cell phones to defense equipment.

Recommendations to Future Researchers

Should future researchers pursue a similar topic, more extensive research on midstream and downstream processes is needed. Super alloys are a broad classification of alloys, which requires expert knowledge on metallurgy of rare earths. The transparency of information and understanding of REE products from midstream to downstream is currently extremely murky at best. This is an inherent problem when researching downstream products.

Another area for further research is the permitting process for mining and separating rare earth projects. The long and extended permitting process is a huge barrier to establishing mines. The USFS is revisiting some of its environmental regulations to determine their relevancy. However, what are some of the other agencies doing to help resolve this barrier? What is the EPA's role in permitting? Will the Environmental Protection Agency be more involved in stopping the production of REEs within the U.S. if the government deems them to be essential for national security? How does each state's utilities commission and Department of Natural Resources help or hinder the permitting process?

Additionally, future researchers should study ways to establish mines, separation facilities, and process plants through environmentally friendly means. Mining 40 metric tons of mineral deposits produces 1 ton of solid waste with radioactive elements, 20,000

gallons of acidic wastewater, and airborne contaminants..¹⁹⁶ When mining operations ceased in China during the COVID-19 pandemic, air pollution essentially dissipated. Places known for their terrible air quality, like China's Hubei Province, had clear skies..¹⁹⁷ The incident demonstrated how the earth can heal itself from years of pollution. How can the mining industry establish environmentally friendly ways to safely extract REEs? Exploration of environmentally safe mining and separation needs to be discussed as well as potential solutions to the unintended consequences of disturbing the earth's crust. Could thorium, an unwanted byproduct of mining, be used for another purpose such as molten salt power plants to power America? Research in these areas could solve the imbalance between the requirement for REEs for green energy and the harmful effects of mining and separation of REEs.

Final Thoughts

There is no simple solution to ending U.S. dependence on China for REEs. The emphasis on innovative technology and renewable energy will increase demand and shorten REE supply for the DoD. As U.S. policymakers and REE companies continue their efforts in expanding the REE industry within the NTIB, it is crucial to diversify upstream mining operations. Investing in establishing mines will positively affect

¹⁹⁶ Lee Simmons, "Rare- Earth Market," *Foreign Policy*, July 12, 2016, <https://foreignpolicy.com/2016/07/12/decoder-rare-earth-market-tech-defense-clean-energy-china-trade/>.

¹⁹⁷ Helen Regan, "Air pollution falls by unprecedented levels in major global cities during coronavirus lockdowns," *CNN News*, April 23, 2020, <https://www.cnn.com/2020/04/22/world/air-pollution-reduction-cities-coronavirus-intl-hnk/index.html>.

downstream production. It will be decades before the U.S. can have a reliable supply chain outside of China. Given the adversarial nature of U.S.-China relations, the U.S. must move in that direction.

It is important that the U.S. economy not be dependent on China for REEs. As this study demonstrates, key sectors of the U.S. economy depend on REEs for many end-products and uses. It is doubly important that the U.S. military not be dependent on China for REEs, which are required to produce the high-tech weapons and equipment needed to fight in the future JOE. During this Great Power Competition, relying on China for lowered tiered supply of REEs to produce U.S. military-grade equipment capable of dealing with future adversaries is illogical. It is a strategic vulnerability that must be removed, and the sooner the better.

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