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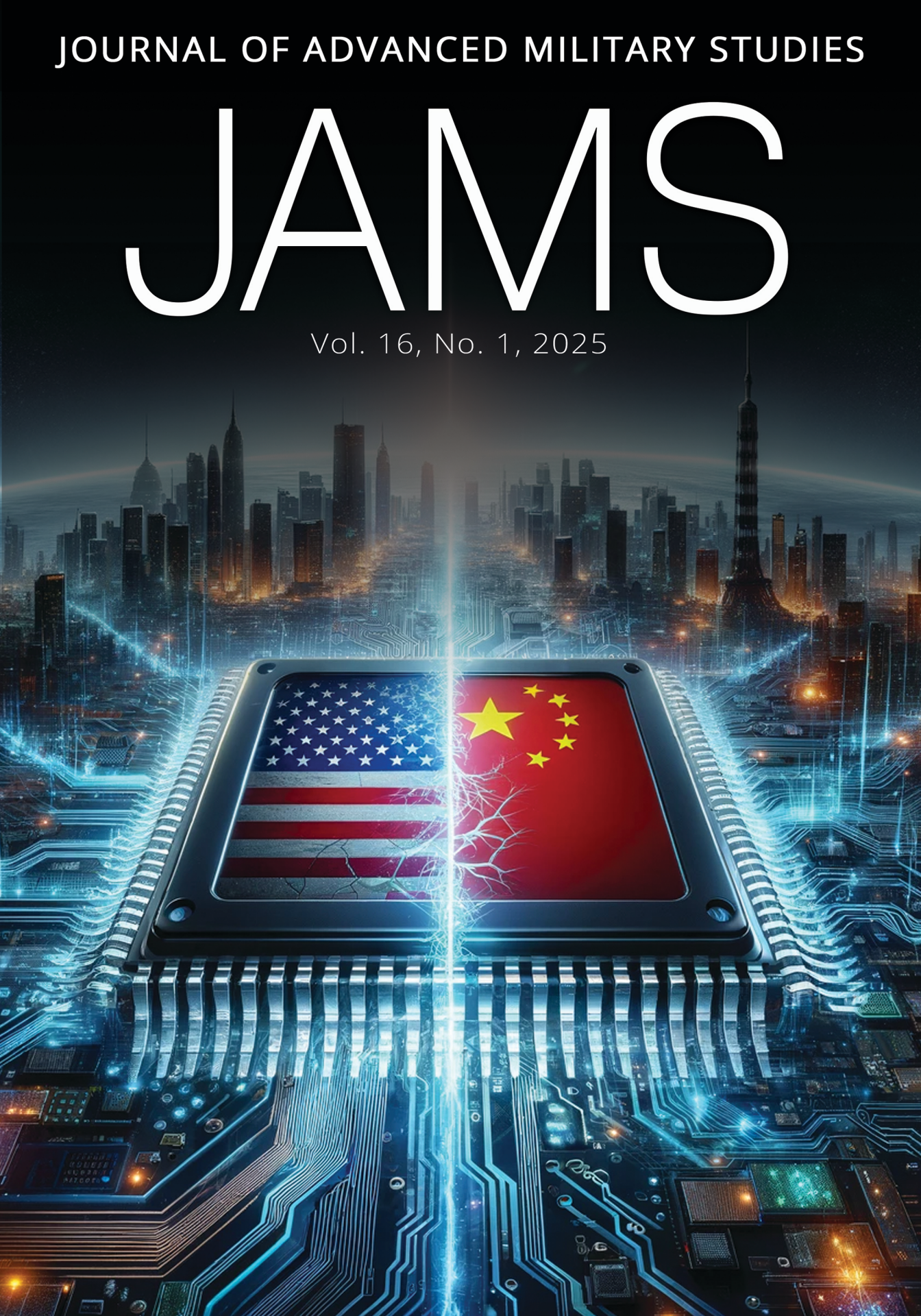

Power Play
Charging Up Strategic Competition over Lithium Battery Value Chains

Major Philip Murray, U.S. Army

Abstract: This article examines the strategic implications of the People's Republic of China's (PRC) dominance over the global lithium value chain and the resulting vulnerabilities for the U.S. Department of Defense. During several decades, through sustained strategic investments, the PRC has achieved a controlling position in the lithium market, encompassing mining, refining, and battery manufacturing. This control allows the PRC to influence lithium pricing and availability globally, posing significant economic and strategic risks to nations reliant on these supply chains, particularly the United States.
Keywords: lithium, batteries, China, strategy, energy, defense

Lithium, often dubbed "white gold," is a critical mineral for national security in both the People's Republic of China (PRC) and the United States due to its essential role in modern technology and energy solutions. Lithium is a highly significant element in modern energy storage technologies due to its unique properties. As the lightest of all metals, lithium has an exceptional electrochemical potential, allowing it to store substantial energy relative to its weight. This attribute makes lithium batteries particularly valuable for portable electronic devices and electric vehicles, where weight and efficiency are crucial. Furthermore, lithium's ability to repeatedly accept and release electrons during charging and discharging cycles contributes to the durability and longevity of

Maj Philip Murray (USA) is currently assigned as a branch chief in the J22 of the U.S. Space Command in Colorado Springs. Maj Murray previously served with the 4th Infantry Division in Afghanistan, Intelligence and Security Command, U.S. Army Pacific, and as an assistant professor of history at the U.S. Military Academy at West Point. He holds a master of history from Georgetown University in Washington, DC, a master of science and technology intelligence from National Intelligence University in Bethesda, MD, and a bachelor's of science in anthropology from Montana State University in Bozeman. https://orcid.org/0009-0006-4945-2069.
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lithium-ion batteries.[1] These properties, combined with a relatively stable discharge voltage, ensure that lithium remains a cornerstone material in the development and optimization of rechargeable battery technology. For the United States, lithium resources and technologies are foundational to national security since they undergird expeditionary military capabilities, power almost all satellite systems, are an integral component in nuclear weapons and fusion nuclear power, and are essential to modern life in American civil society. Even with their clear importance, the United States failed to recognize the strategic value of lithium early on and is now in a precarious situation of strategic weakness regarding key aspects of the lithium value chain and associated technologies.

No other nation has recognized the value of lithium as much as the PRC. During several decades of investment, the PRC gained a strategic advantage over global lithium value chains. Their advantages in the lithium market permeate through major stages of the lithium value chain, from extraction and refining to manufacturing. As a result, most nations are now almost completely reliant on the PRC for the critical manufacturing materials and lithium-ion batteries. Given the PRC's demonstrated willingness to impose trade tariffs and restrictions, as evidenced by recent measures on gallium and 17 other rare earth minerals, the strategic risks of continued reliance on the PRC for lithium become increasingly clear for nations like the United States.[2]

The U.S. government and industry rely on lithium-based technologies for many strategic capabilities and initiatives. Modern military operations rely on rechargeable lithium-powered batteries for communications, sustainment, transportation, and increasingly for drones and direct/pulse energy weapons as well. Every part of American society depends on thousands of lithium batteries in satellite constellations, which harness energy from the sun to enable position, navigation, and timing (PNT) technology, satellite communications, meteorological data, remote sensing, and intelligence collection on adversaries. Lithium 6, when bombarded by neutrons in a reactor, produces the radioactive isotope tritium, an essential ingredient in both nuclear weapons and emerging fusion energy projects. Additionally, it is required for all the devices in American homes and offices that operate on rechargeable lithium batteries. On 30 September 2020, Executive Order 13953, "Addressing the Threat to the Domestic Supply Chain from Reliance on Critical Minerals from Foreign Adversaries and Supporting the Domestic Mining and Processing Industries," mandated that securing lithium supply chains free of Chinese control is a national security priority.[3] Given the strategic nature of lithium and the U.S. government's clear admission of the importance of lithium in multiple policy documents and executive orders, how did the United States cede this advantage to the PRC?

In part, the answer lies with the adoption of electric vehicle (EV) manufacturing. In contrast to the hesitant adoption of electric vehicles in the United

States, the PRC fully embraced the EV transition in transportation and achieved 38 percent of market share of sales for new vehicles in 2023 and 60 percent of all new EVs worldwide were Chinese manufactured.[4] The PRC was an early adopter of EV technologies to reduce their overall petroleum imports and stabilize their energy security away from reliance on imports.[5] The adoption was top-down and not market driven, starting shortly after the East Asian market crisis of 1998 and involved a $14.7 billion dollar investment in the electric vehicle industry by state owned industries.[6] Within a short amount of time, the PRC emerged as a global leader of EV manufacturing and sales, and by necessity of that industry, a leader in lithium battery technology manufacturing.

The PRC has consistently invested in the lithium processing supply chains irrespective of prices, which was always aimed at fueling the auto industry, reducing petroleum imports, and leading lithium technology versus delivering on stockholder returns—the typical priority for capital-driven market economies.[7] The PRC understood early on that some commodities are worth more than their cost due to their importance to national security. The PRC's strategy has decreased the number of market competitors in the industry through artificially low lithium prices and tight market control of most downstream activities involved in refining lithium into usable materials (99.6 percent purity lithium hydroxide and lithium oxide). Pursuit of this strategy resulted in enormous waste in the form of unprofitable state-owned companies, but it also earned the Chinese dominance within the entire lithium value chain.[8]

How the PRC's Lithium Chain Put the United States in a Bind

So why does it matter to national security in the United States if the PRC is the leader of lithium value chains and EV manufacturing? As the world's leader in EV manufacturing and exporting, the PRC has gained the industrial capabilities to lead all associated lithium battery industries. The advantage of leading the EV industry and market is that the costs associated with smaller lithium technologies (e.g., those used in portable electronic devices and phones) are subsidized and reduced by the massive scales in which the PRC orders raw materials and manufactures components. For decades, American-led globalization prioritized cost savings and efficiency over supply chain security for most resources, leading to huge export profits in lithium technology for the PRC. This dominance has translated into American industries' reliance on PRC lithium value chains, which are inarguably the cheapest and most cost effective, but also represent the greatest strategic risk to the U.S. Department of Defense technology acquisition value chains in the face of emerging global tensions.

The evidence of the PRC's dominance in the lithium value chain is well represented in the International Energy Agency's (IEA) statistics and projec-

tions for growth. As of 2023, the PRC retains 65 percent of the world's lithium refining capacity, 1.20 terawatt-hours (TWh) of the global 1.57 TWh battery manufacturing capacity, and 1781 gigawatt-hours (GWh) of 2173 GWh EV battery manufacturing is either in the PRC or owned by a PRC company.[9] In 2023, the PRC exported $9.8 billion (USD) in manufactured batteries to the United States—a number that has almost consistently doubled annually since 2018.[10] Also, with control of 156 out of 211 mega lithium-ion battery factories worldwide, the PRC possesses a gravitational weight on the market of raw lithium sales that took decades to establish and will not be easily displaced.[11]

The PRC's commanding lead of the lithium-ion technology market and a willingness to defy market trends with state-owned industry subsidies are a massive strategic advantage in the lithium value chain competition. Current projections in industry estimate that the PRC will control upward of 35 percent of the global extraction supply chain outright, even more through shared ownership, and account for 60 percent or more of the global refining by the beginning of 2025.[12] IEA projections estimate that 74 percent of manufacturing capacity of lithium batteries will be in the PRC by late 2025.[13] Relying solely on market forces and profit-based decision-making, the United States and its allies cannot overtake the PRC in most aspects of the lithium value chain, especially considering that the U.S. Department of Defense only commands approximately 1 percent of American market demand for batteries and many are used for critical expeditionary functions.[14] Any instance of a prolonged trade war with export restrictions on manufactured lithium technology, or outright conflict with the PRC, could put U.S. Department of Defense capabilities at risk.

In several scenarios, the U.S. Department of Defense could lose critical capabilities due to the PRC's dominance of lithium value chains and/or could be cut off from some variants of lithium batteries only manufactured in East Asia. These scenarios range from intense conflict between the two nations and a potential trade war, to more severe outcomes like the demographic and economic collapse of the PRC, as predicted by prominent geostrategist Peter Zeihan.[15] From the United States' perspective, the current sources of downstream lithium technology represent a strategic risk to national security capabilities. The United States either needs to accept this current arrangement and inherent risk or actively seek to develop new sources of lithium refining and manufacturing to support Department of Defense capabilities.

This article outlines the risks and opportunities for the United States and Department of Defense vis-à-vis the PRC's value chain dominance across the mining, refining, manufacturing, and emerging technology sectors. The United States is at an extreme strategic disadvantage in the lithium value chain when it comes to Department of Defense capabilities and acquisition, but these disadvantages have clear short- and long-term solutions.

Geopolitics of Lithium Extraction

Among the extracted raw lithium resources in the world, most of the hard rock mined sources and more than one-half of the lithium carbonate from brine are used in the PRC.[16] The PRC's demand for raw lithium is a powerful strategic asset when it comes to shaping the market, but also a strategic vulnerability since all the capital investments further downstream of the lithium extraction rely on continued supply. Lithium is an abundant resource in the lithosphere around the world, but not every source is economically feasible for extraction to bring to a refinery. Raw lithium is the part of the value chain the United States is best positioned to compete and seek alternatives outside the PRC value chain because of its low cost and abundance.

The most economically feasible locations for lithium extraction are geographically concentrated in such a way that there are clear blocks of producers and consumers. The current global market for lithium greatly favors the PRC since they are the market of choice for exporting nations and are third in the world for mining lithium. With 90 percent of unrefined lithium originating from Australia, Chile, and the PRC, the market is heavily concentrated in a few nations.[17] The "Lithium Triangle," which includes Argentina, Bolivia, and Chile, collectively possess the world's largest concentration of lithium in salt lakes—this makes them the geographic center for future strategic competition over lithium resources. The PRC has already made important inroads in all the Lithium Triangle markets, including an exclusive contract with Bolivia, which has long struggled to develop its industries.[18] The PRC enjoys a comfortable, strategic advantage in the quest for ownership of the world's lithium mines and continues to invest in diverse sources to gain value chain security, but the competition in this sector provides opportunities for challenges to their strategic position in the value chain.

According to the National Mining Association, the United States imports roughly 25 percent of its lithium needs—most of the import sources are from the Western Hemisphere.[19] Already, United States' Albemarle has secured salt flat brine mining rights in Argentina and invested in the development of several domestic mines.[20] Combining the estimated imports from foreign sources from the U.S. Geological Survey statistics with the National Mining Association import estimates places American production at around 13 million tons of lithium in 2022. This would make America the fifth leading producer globally behind Australia, the PRC, Chile, and Argentina.[21] This means that raw lithium is not much of a strategic vulnerability for American consumers due to the reliability of the trading relationships and number of lithium reserve sites within the Western Hemisphere.

When it comes to market power, the United States does not hold as much power over producers as the PRC and this cedes important market advantages

in the mining sector of the lithium value chain. Combined with imports, American lithium consumption is around 15.4 million tons a year. Comparatively, the PRC is the largest consumer of unrefined lithium with their net consumption around 37 million tons in 2023—33 million mined domestically and 4 million imported.[22] The PRC's main trading partners for imports are Australia, Brazil, and Zimbabwe.[23] The United States and the PRC are key players in the competition for unrefined lithium resources, but the PRC's dramatic 1.5 times overall consumption and double import demand give them a significant advantage as the premier market of choice for raw lithium.

PRC diversification of sources for lithium imports is viewed as a strategic hedge against risk and their state-owned industries work to secure advantages through a variety of methods. Examples of the PRC's strategy to secure lithium resources abroad for their massive lithium value chain industry abound—the PRC retains 25 percent of Sociedad Química y Minera de Chile (SQM) controlling shares and the Chinese lithium refining giants Ganfeng and Tianqi Lithium control between 40 percent and 51 percent of shares of most Australian mining interests such as the mines in Greenbushes and Mount Marion.[24] The growth of the Australian and Chilean lithium industries are due in part to Chinese demand and investment, so the presence of Chinese capital is not surprising. The other sneaky method to secure resources abroad by the PRC is evidenced in examples like Zimbabwe, where the state's public and publicly guaranteed debt (PPG) exceeds $12 billion to the PRC and are often repaid in the form of guaranteed commodities pricing and deliveries.[25] Reliance on foreign imports, much like the PRC's reliance on petroleum, fuels the desire of PRC economic planners to continue diverse investments abroad for more controlling shares in all sectors of the value chain. Much like their strategy for oil, which includes developing domestic production and discovering proven reserves, the PRC's lithium value chain strategy includes securing resources from a variety of actors across the globe to insulate from geostrategic risk.[26]

One of the reasons the PRC finds willing and accessible partnerships around the globe is the nature of the unrefined lithium market. The price fluctuations based on demand from quarter to quarter and year to year are difficult to forecast, which makes investment in new mines risky from a free-market investment model. One only need look at the recent price collapses in 2023 and 2024 to see why new mines are struggling to secure financing or are being absorbed by larger mining conglomerates at bargain rates.[27] The prices for lithium have increased steadily alongside PRC manufacturing output since 2018, but now the massive glut in raw lithium exceeds global refining capacity.

The price collapse has driven many of the smaller mines out of operation and scared away venture capital from further investments at present, even though market watchers like Benchmark expect demand to surge in the next

decade.[28] The PRC also decreased its lithium extraction to keep prices stable, to no avail.[29] This makes the market hostile to new start-ups without large state sponsors since the return on investments is not guaranteed and vulnerable to market shocks. This particularly applies to the United States, where plentiful amounts of new raw lithium have been discovered, but banks and local communities are hesitant to support domestic mining for both economic and ecological reasons.

Despite shaky markets, long-term projections for lithium extraction profit margins are favorable during the next decade and beyond. Market forecasts from both the International Energy Agency and McKinsey & Company anticipate average growth in lithium battery value chain to increase 30 percent annually from 2022 to 2030 and stabilize in price growth until 2045.[30] The likelihood that the boom-and-bust trend of the lithium market continues is high given the current market arrangements with distinct separations in the value chains, from extraction all the way to EV car sales. This adds significant risk in any nonsubsidized capital investments and favors large established mining majors. Conservative estimates place the potential annual profit in future lithium value chains at $400 billion by 2030—a significant value for entities like the PRC who have continued investment despite market demands and trends that keep new capital and private equity out of the market.

Recycled lithium offers a strategically attractive source for raw lithium outside of the mining industry as well. "Urban mining," as described by a prominent lithium market analyst at the London metals exchange, Lukas Bednarski, needs to be considered another source of raw lithium and, more importantly, other rare minerals used in battery components.[31] The largest lithium recycling company operating now is Umicore's factory in Hoboken, Belgium—other notable mentions are Canadian Li-Cycle, American Redwood Materials, and Chinese firms like CATL's recycling wing, Brunp.[32] With an average life expectancy of 8–10 years, there is going to be a steady stream of EV engines ready for recycling by 2030 with an average of 17 pounds of lithium from each engine.

Challenges remain in the recovery process of lithium batteries since they always retain a charge and come in a variety of sizes and shapes, which makes streamlining recycling difficult. Furthermore, the relative cost of raw lithium depresses the recycled lithium market. Recycled lithium costs more per pound, which makes profitability difficult in a market with record low prices, and recycled lithium still requires refining.[33] Another reason is that the processes are still insufficient for finding, transporting, and integrating used lithium batteries into the recycling plant. Even if they do make it there, they come in all sizes and charges, which require special equipment. Further complicating the matter is that, according to economist Ed Conway's interview with Umicore represen-

tatives, the recovery rates for lithium from EV engines currently sits at around 50 percent.[34] Greater incentives and developments are needed to make urban mining profitable.

Recycling offers a greater amount of security for the supply chain at a higher cost for the United States, but also the abundance of raw lithium is not necessarily the issue for national security concerns. The strategic value of recycled battery recovery may pay greater dividends for the rare earth minerals included in batteries, such as cobalt, that the United States is completely reliant on imports for. However, incentives for rare earth metal recovery from batteries also mean more secure sources of lithium for domestic production in the United States.

For the United States and the Department of Defense, increasing reliance on domestic industry and securing recycled lithium sources offer viable solutions to mitigate supply risks. Implementing procurement policies favoring recycled lithium, subsidizing the integration of recycled lithium into domestic manufacturing, and potentially creating state-owned recycling/refining operations for defense use could enhance supply chain resilience. This approach aligns with broader economic policies aimed at reducing dependency on foreign sources and enhancing national security amid global competition for critical minerals. However, these measures require federal commitments to domestic lithium industries to overcome challenges related to cost fluctuation and easing integration into existing manufacturing processes. Further increases in domestic mining without concurrent investments in refining capacity only benefit the PRC, who will retain their position as the premier market for unrefined sources. These moves would not only challenge PRC dominance but offer defense contracted companies and allies alternative supply chain sources with greater security and reduced risk.

Refining Solutions to Lithium Supply Choke Points

Lithium is practically useless without refining into a purity level that enables its use in manufacturing, hence the abundance of lithium resources across the world are useless without refining capacity. The PRC dominates the refined lithium market as the leading consumer and the leading exporter—a rare combination of titles in the commodities market.[35] The PRC accounts for 65 percent of the world's refining capacity, Chile accounts for 26 percent of refined lithium, Argentina accounts for 5 percent, and the rest of the world is about 4 percent.[36] The PRC's significant demand for refined lithium consumption and exports gives them not only a powerful strategic advantage over commodity pricing, but also leverage in trade conflicts or negotiations with any nation hoping to manufacture lithium batteries. Understanding the significant advantages the PRC

enjoys from their capital investments in lithium refining capacity are necessary for adapting to the challenges they pose in securing lithium-ion battery value chains for the United States.

Even though the PRC can produce 89 percent of required raw material requirements domestically, an inability to export refined lithium would cripple their lithium refining industries. To insulate against risk of competition, PRC companies such as Ganfeng Lithium and Tianqi Lithium have secured long-term supply contracts and equity stakes in major lithium projects in the two chief competitors for refined lithium, Chile and Argentina.[37] In 2022, the PRC was responsible for 76.7 percent of the entire $5.4 billion export trade of lithium hydroxide, which is up 346 percent in value from $1.21 billion in 2021.[38] Top destinations for their exports were the remaining top battery manufactures such as South Korea, Japan, and a smattering of other East Asian/South Pacific nations along with Sweden.[39] Their ownership and equity shares around the globe ensure long-term security and hedge against supply chain disruptions in a multitude of geopolitical scenarios.

The PRC's advantages are not permanent in the refining sector. The IEA already anticipates their controlling share of refining capacity to decrease to 49 percent by 2030 as other leading competitors like Albemarle in the United States increase their global operations.[40] Blocs of consumers like the European Union are already working to reshape economic law to favor domestic industry and decrease reliance on PRC suppliers by implementing laws that heavily tariff or block industries with state subsidies.[41] In the United States, the Inflation Reduction Act of 2022 added regulations to subsidize lithium from North American refiners for use in EVs, along with generous Department of Energy loans for new refining capacity, which has spurred new construction in places like Texas and Nevada.[42] But with the continued control of the market from decades of investment, those seeking to disconnect or challenge the PRC's control must expect to weather through PRC overproduction and market volatility for value chain security in lithium technologies.

Options to mitigate a short-term risk in refined lithium supplies are less palatable. The United States must be prepared for a strategy like the historical management of petroleum supplies, which involved public-private partnerships and strategic resource distribution during World War II. Establishing an office akin to the former National Recovery Administration's oil code or the Office of Petroleum Coordinator could help manage lithium supplies effectively.[43] In the long term, expanding domestic refining capacity and aligning with allied markets to prefer secure supply chain refined lithium exports are crucial steps to securing the value chain against future disruptions.

United States Leading the Charge for Allied Battery Manufacturing

The rapid growth of the PRC's EV sector, supported by robust government incentives, positions it as the largest consumer and exporter of lithium batteries globally. The integration of lithium refining and battery production within China reduces costs and enhances efficiency, providing a competitive edge over other nations. The sheer volume of refined lithium used in the PRC's EV industry also decreases the cost of smaller battery manufacturing to price averages well below what is feasible for any other nation to accomplish. It is no coincidence that 74 percent of lithium battery manufacturing occurs in the PRC and more than 80 percent of the global lithium battery manufacturing capacity exists in East Asia with reliance on PRC refined lithium products.[44] This trend is further reinforced by the South Korean and Japanese reliance on PRC refined lithium products for their microelectronics industries as well.[45]

During the past decade, the Chinese government has allocated more than $60 billion in subsidies to support EV production and infrastructure development.[46] These subsidies were pivotal in reducing initial production costs, weathering market fluctuations, and encouraging consumer adoption. Additionally, the government has invested heavily in research and development, pouring approximately $2.4 billion into EV-related technology advancements.[47] This aggressive financial backing has propelled China to become the world's largest EV market, with more than 1.3 million electric cars manufactured in 2020 alone, accounting for more than 40 percent of global EV production and 60 percent of EV sales.[48] The PRC's strategic use of subsidies and investments has thus far established it as a dominant force in the global EV industry, fostering a robust manufacturing ecosystem that continues to grow rapidly without subsidies and organic consumer demand.

Simple analysis leads many to conclude that the PRC's dominance in EV manufacturing is a result of the meticulous capitalism with Chinese characteristics emblemized by the "Made in China 2025" plan or through reckless hyper-financing and spending in all manufacturing sectors that will likely implode.[49] However, the real impetus for the massive investment in EV manufacturing stems from the PRC's colossal energy security issues derived from leading the world in petroleum and hydrocarbon imports through geostrategic choke points controlled by the United States' Seventh Fleet.[50] From the perspective of Chinese Communist Party leadership, every EV on the road is a few less barrels of oil they need to import. The year 2022 was in fact the first year the PRC's imports of foreign oil did not increase since 1991—although there are more than just EVs as a variable in this trend.[51] Thus far, the PRC's calculated investment or gamble, depending on one's perspective, has paid off with dividends in the lithium battery and EV value chains.

EVs capture the bulk of attention since they are a key emerging technology in strategic competition and the green energy revolution. Focus on EV manufacturing is important since it acts as a subsidizing market force for all other lithium battery manufacturing and explains the PRC's strategic position of strength in global manufacturing across the value chain. EV procurement and/or technology are not a strategic vulnerability for the United States, since the domestic industry has flourished under protective tariffs against foreign EV manufacturers. However, the strategic risk in other lithium technologies that benefit from the PRC's robust lithium supply chains are pronounced.

American companies are well positioned to compete at the high end of lithium battery manufacturing (EV engines) but ill-suited to compete with East Asian manufacturing for the lower end (personal electronics and other lithium-ion applications smaller than EV engines) of the market.[52] The United States is the leading importer of lithium-ion batteries with a total import cost of $13.9 billion in 2022, with $9.3 billion coming from the PRC.[53] The lower end of the lithium battery market is where most of the ubiquitous and important lithium batteries for portable electronic devices and drones are manufactured. Thus, the clearest vulnerability in the supply chain from the perspective of the U.S. Department of Defense are smaller lithium batteries, which power critical technologies such as communication devices, handheld GPS, drones, and other expeditionary technologies that the defense industry sources abroad.

As with most of the world, the Department of Defense's lithium value chains are also primarily located in East Asia, posing a strategic challenge. According to the Department of Energy, it procures approximately $200 million of all battery types each fiscal year. Assuming the majority of these are lithium for the purposes of this thought experiment, the Department of Defense's purchases makes up approximately 1.44 percent of all American lithium battery import demands.[54] The Department of Defense's market share of all U.S. lithium battery consumption is likely less than 1 percent.[55] When it comes to batteries, the Department of Defense procurement processes are entrenched in the globalized supply chain mindset of cost-saving manufacturing over supply chain security.

The Department of Defense's inability to leverage market power and robust need to procure a vast array of battery types poses a significant challenge to securing critical lithium value chains for defense. A shortage of lithium, even for a year, has massive implications for Department of Defense capabilities. One need only look at the one- to two-year life cycle of a portable radio or GPS rechargeable lithium battery under heavy use to understand how a disruption to the supply could impact capabilities at all echelons. Every charge and discharge of lithium battery decreases its life cycle, and given that infantry squads, vehicles, and command posts all rely on personal electronic batteries, the loss in

communications and capabilities without a resupply of lithium-ion batteries to replace expended batteries impacts all formations from the team level up from the U.S. Army and Marines' perspectives.[56] This does not even include risks associated with the capabilities and opportunity loss the Department of Defense would incur from other lithium batteries necessary for emerging drone and energy pulse weapons capabilities. More needs to be done to ensure the entire value chain for Department of Defense batteries. The solution to this problem lies with greater efforts to support allied and North American suppliers.

In the long term, blocs of lithium battery consumers, like the United States, can continue their plans to increase their market power by mandating standardization of lithium battery manufacturing, which eases the value chain complexity and decreases the pressure for manufacturers to seek specialty batteries overseas.[57] Focusing allied manufacturing on smaller sets of standardized lithium batteries increases the ability to foster their growth and decouple from PRC manufacturers. This effort requires collaboration between technology manufacturers and battery manufacturers for adoption and standardization. The Department of Defense has a role to play in this process by shaping contracts to mandate battery adaptability, much like prime power contracts mandate procured technology to work with existing Department of Defense generators.[58] This effort can shape the market by influencing leaders of national security hardware and eventually other sectors of the economy will adopt the standardized batteries to secure supply chains and reduce risks.

A potential strength for the United States and allies in the current strategic environment is that the vast multitudes of bespoke and specialty batteries in the current supply chain are nearly impossible to leverage effective sanctions without hamstringing most of the PRC's lithium exports. Furthermore, limiting Japanese and Korean manufactures access to refined lithium to stop United States and allied defense industry battery procurement would likely backfire and lead to increases in challengers to the PRC refining market advantage. Any attempt to curb the export of small batteries to specific defense industries around the world would cause the PRC to incur more economic loss and hardship than the United States would lose in capabilities.

A long-term solution readily available is for American grants or subsidies to include stipulations for battery manufacturing recipients to build some capacity in their EV factories for low-end market lithium-battery manufacturing. Most American manufacturers are currently seeking to enter the profitable EV manufacturing market, but capacity for ubiquitous lithium batteries needed for portable electronics are rarely a profitable business model outside of East Asia. Benchmark Minerals anticipates more plans for American and allied gigafactories to pull out of their investments in the wake of softening prices in 2024.[59] At a minimum, the Department of Defense can mandate not only a

standardization of batteries for new contracts, but also mandate those battery come from secure U.S. and allied supply chains—a clear trade-off for security over cost. Regardless, the world outside of the PRC sphere can expect value chain secure batteries to exceed the average costs of East Asian manufacturing by a wide margin.

In the short term, if the United States were unable to procure materials from East Asian manufactures, the options for securing critical battery supplies are less palatable. Options include using third parties abroad to secure PRC batteries in a similar fashion to how Russia has attempted to bypass trade control sanctions.[60] Also, in a conflict, nations could follow historical precedence for a technology swap mid-conflict, similar to how England traded rubber to Germany in exchange for rifle scopes and binoculars during World War I.[61] Both of these options are highly undesirable, but considering an immediate crisis in the current arrangement, there are no good options.

Leapfrogging Lithium: Sodium-Ion Batteries and Alternative Technologies

Given the marked disadvantages the U.S. Department of Defense faces in the lithium value chain, alternative technologies represent a bright spot of optimism for greater security and capability. Sodium-ion batteries (Na-ion) are emerging as a potential alternative to lithium-ion batteries (Li-ion), driven by various factors including cost, supply chain security, safety standards, and performance. However, even with many redeemable qualities, the capital investments in sodium-ion manufacturing are nowhere near maturity, and there are performance considerations introduced below that make them unable to replicate some capabilities of lithium-based technologies. Solid-state lithium batteries also offer the possibility to eliminate reliance on the many battery components that the PRC currently controls such as graphite and other rare minerals like cobalt, which are located in a few geopolitically sensitive areas.[62] Other older and existing battery technologies such as zinc, alkaline, and acid batteries are capable of replacing some lithium applications but are unlikely to make major replacements without massive scale-ups in manufacturing and research and development to increase efficiency that will take years or decades. Sodium-ion and other batteries are going to be a part of the solution to achieve greater supply security, but they offer little help in the interim. More research and development, investment in manufacturing, policy adjustments to favor allied industries, market development, and most importantly time are needed to replace lithium-ion technologies.

Sodium-ion batteries present a promising alternative to lithium-ion batteries in large, fixed-site applications, offering significant advantages in terms of cost, supply chain security, and safety. They currently lag behind lithium-ion

batteries in terms of energy density, portability, and size. Just like zinc, alkaline, and classic lead acid batteries, sodium-ion batteries will find their place in the supply chain and eventually decrease reliance on lithium in some sectors. The broader adoption of sodium-ion technology stands to reduce dependence on critical minerals, enhance national security, and provide a safer and more sustainable energy storage solution in key areas.

As the technology matures, sodium-ion batteries, solid state batteries, and others are likely to complement rather than completely replace lithium-ion batteries in various applications. The manufacturing processes for these alternative batteries are still maturing, requiring substantial initial investments in infrastructure and technology development. The pathway dependency on lithium induced by decades of PRC investments and now lower costs for materials, combined with lithium tech's increasing performance efficiency, make any total replacement scenarios a far-fetched solution for the immediate demands of the U.S. Department of Defense and allies.

Conclusion

In the age of strategic competition with the PRC, the United States has already suffered one of its largest failures by recognizing the strategic value of lithium technology value chains too late. Strategic resources like lithium technology are worth more than their market value since security of the value chain must be ensured to access them and for the critical capabilities they enable. In the era of strategic competition with the PRC, security of value chains once again has returned as the primary consideration for commodities over price.[63] The United States has long recognized the strategic value of petroleum and hydrocarbons within this paradigm of understanding but seemingly overlooked lithium technology. U.S. policy makers and industry continued to prioritize prices in the lithium value chain while the PRC recognized lithium's strategic value decades before. The U.S. Department of Defense has now fallen into a position of strategic disadvantage within the lithium value chain that will take immediate and dramatic actions to reconcile.

From the U.S. perspective, the lithium value chain is a strategic disadvantage, but not an irreconcilable one. Long-term solutions included in the Inflation Reduction Act and the 2022 activation of the Defense Production Act by the Joseph R. Biden administration are already working to scale up domestic capacity across the value chain, which ultimately addresses many vulnerabilities. It is currently unknown how these initiatives will fare under the Donald J. Trump administration, but even with these solutions, the Department of Defense requires immediate solutions like the ones recommend above to secure critical capabilities enabled by lithium technologies.

In the event of a short-term crisis or dispute affecting lithium value chains,

the severe repercussions of the Department of Defense's strategic disadvantage in lithium would become starkly evident. Suppliers could face a shortage of portable electronics and access to critical lithium refining capabilities and resources. The crisis options available, already mentioned in this argument, are less desirable but are a necessity in the current strategic environment. Despite operating from a position of distinct strategic disadvantage, the United States has options for countering the strength of the PRC's control over the lithium value chains to secure critical capabilities.

To impact the PRC's long-term advantages, more analytical work is needed to uncover areas for strategic opportunities from the perspective of the United States. Comprehensive engagement with top suppliers in the Lithium Triangle are needed to weaken and/or replace the PRC's influence on their major suppliers and market competition. Further research on the political economies of Argentina, Chile, and, maybe most importantly, Bolivia is needed to inform decision-making on opportunities and challenges for competing with the PRC in these critical lithium supplies and refiners. Another area for research to complement these findings include finding emerging battery technologies that could replace key value chain vulnerabilities associated with lithium technology—such technologies are likely a decade or more away from commercial viability but represent emerging strategic opportunities that are vital to pay attention to now so that the United States' lithium missteps are not repeated.

Endnotes

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