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Industry Study**

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*Strategic Materials***



The Industrial College of the Armed Forces
National Defense University
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STRATEGIC MATERIALS 2007

ABSTRACT: The ability of U.S. defense firms to gain reliable, timely, and affordable access to the materials needed to produce defense products is critical to our national security. When the supply of materials required by these firms becomes vulnerable and no material substitutions are available, the material can be classified as *strategic*. These strategic materials warrant scrutiny to ensure associated risks are mitigated. A close examination of the *light armor* industry serves to demonstrate the importance of strategic materials, describe dynamics of this industry, and reveal needed adjustments to government policy that can reduce strategic risk and enhance our national security.

Col Eddie Adelman, US Air Force
Lt Col Cassie Barlow, Ph.D., US Air Force
CAPT Eric Chamberlin, US Coast Guard
Col James Fulton, US Air Force
Mr. Jim Galvin, National Security Agency
CDR Chuck Good, US Navy
Ms. Sue Goodyear, Dept of the Army
COL Igor Kosiak, Ukrainian Army
Col Mike Moran, US Air Force
LTC Tom Ockenfels, US Army
LTC Gregg Skibicki, US Army
LTC Penny Speed, US Army
Ms. Maria Thorpe, Dept of the Navy
BG Mahdi Yosuf, Malaysian Army

Dr. Sylvia Babus, Faculty
Mr. John McShane, Faculty
Col Jeff Patterson, US Marine Corps, Faculty
Dr. Irene Kyriakopoulos, Faculty
Dr. Gerald Abbott, Faculty

PLACES VISITED

Domestic:

Armor Holdings, Advanced Research and Development Facility, Detroit, MI
Armor Holdings Incorporated, Specialty Defense Products, Dunmore, PA
Army Research Laboratory (ARL) Weapons & Materials Research Directorate, Aberdeen, MD
Army Research Laboratory (ARL) Armor Mechanics Directorate, Aberdeen, MD
Center for Composite Materials (CCM), University of Delaware, Newark, DE
DuPont Industries, Richmond, VA
Foster-Miller Incorporated, Waltham, MA
Institute for Soldier Nanotechnologies, Massachusetts Institute of Technology, Cambridge, MA
Tank Automotive Research, Development, and Engineering Command, Detroit, MI
Saint-Gobain Crystals, Milford, NH
Saint-Gobain High Performance Materials Research and Development Center, Northboro, MA
Saint-Gobain Ceramics, Refractories Plant 6, Worcester, MA
Saint-Gobain Performance Plastics, Merrimack, NH
US Army Soldier Support Center, Natick, MA
United States Geological Survey (USGS), Minerals Information Team, Reston, VA

International:

Armor Products International Ltd, Armor Holdings, Bolton, England
European Aeronautical Defence and Space (EADS) Corporate Research Center, Ottobrunn, Germany
Electroschmelzwerk Kempten GmbH (ESK), Ceradyne Incorporated, Kempten, Germany
Eurocopter, Donauwörth, Germany
MTU Aero Engines, Munich Germany
NP Aerospace, Ltd., Coventry, England
Technical University Munich, Munich, Germany
Bauhaus Luftfahrt, Munich, Germany
Titanium Metal Corporation (TIMET), Witton, England

The Challenge of Strategic Materials

Security is the priceless product of freedom. Only the strong can be secure, and only in freedom can men produce those material resources which can secure them from want at home and against aggression from abroad.

~ B. E. Hutchison, 1930s industry leader

The majority of government policy on military weapon systems acquisition addresses end items such as tanks, planes, ships, satellites, networks, etc. Industrial analysis by government seldom goes below the subcomponent level, but deeper looks reveal that the weapons systems on which we depend are constructed of specialized materials that are subject to limited availability, high cost, and varying quality. When a particular material is critical to the production of a defense item and the material supply is vulnerable, the material is classified as *strategic* and subjected to closer scrutiny of its associated issues. If necessary, the government will implement specific policy measures to mitigate the risks and potential vulnerabilities. To properly scope and assess the policy issues and industrial challenges associated with strategic materials; this paper will define the nature of strategic materials and explain our focus this year on the light armor industry. The paper will then define the light armor industry, analyze the associated market, and highlight current and future challenges for both government and industry within this market, to include an exploration of relevant legislation and government policy. Because the families of materials essential to the light armor industry are quite broad, several essays will explore relevant material types. Finally, our study will conclude with recommendations to minimize the national security risks and ease the strains on industry driven by the dynamics of strategic materials.

What is a Strategic Material?

As early as 1833, geologist George Featherstonhaugh linked mineral availability with national defense. He suggested to Secretary of War Lewis Cass that a geological map of the United States be commissioned and then taught to West Point cadets (DeYoung, McCartan, & Gambogi, 2006, p. 483). Two decades later, Commodore Matthew Perry's expedition had as one of its goals the testing of Far East coal deposits for future use by the Navy (Morgan, 1984, p. 59). The scarcity of manganese, potash, tin, tungsten, and other minerals during World War I brought the concept of strategic materials to the forefront (DeYoung, et al., 2006, p. 483), leading to the U.S. Army General Staff's 1918 promulgation of the so-called Harbord List of forty-two materials critical to military planning (GSW, n.d., ¶6). In 1939, Congress passed the Strategic Materials Act allowing the U.S. Army and U.S. Navy to determine which materials to stockpile. Congress later enacted the Strategic and Critical Materials Stock Piling Act of 1946, the foundation for current stockpiling law (GSW, n.d., ¶9). In 1985, a Congressional source explained a strategic material as "one for which the quantity required for essential civilian and military uses exceeds the reasonably secure domestic and foreign supplies, and for which acceptable substitutes are not available within a reasonable period of time" (OTA, 1985, p. 11).

In a similar vein, the President in a 1994 executive order defined strategic materials as those that are "(1) needed to supply the military, industrial, and essential civilian needs of the United States during a national security emergency, and (2) are not found or produced in the United States in sufficient quantities to meet such need and are vulnerable to the termination or

reduction of availability” (EO 12919, 1994, §901). Not surprisingly, the Department of Defense’s (DOD) 2001 definition describes strategic materials in light of defense needs, specifying those “required for essential uses in a war emergency, the procurement of which in adequate quantity, quality, or time is sufficiently uncertain, for any reason, to require prior provision of the supply thereof” (JP 1-02, 2001, p. 512).

These definitions, though differing in detail, share two common elements: criticality of application (lack of substitutability) and vulnerability of supply (domestic sufficiency). These elements do not always dovetail neatly with commercial criteria that typically emphasize value using terms such as “rare” or “precious.” Not all strategic materials are rare or precious, and not all precious or rare materials are strategic. In fact, a strategic material may be relatively commonplace in absolute terms. For example, titanium is the 10th most abundant material in the earth’s crust; nevertheless, its strategic value lies in the lack of readily available substitutes in critical aerospace and military applications and shortfalls in domestic titanium metal production capacity.

International strife in the second half of the 20th century made U.S. materials policies appear prescient. The Communist takeover of China ended access to that country’s minerals for over 40 years, and the Cold War gave rise to fears that the USSR would block access to raw materials critical to U.S. national defense. Such a constantly changing geopolitical situation demands our vigilant attention to the national security implications of materials.

The Industry Defined: A Focus on Light Armor

Having defined strategic materials, we face the challenge of approaching a topic of such breadth systematically. Unfortunately, there is no clear-cut “Strategic Materials Industry” in any conventional industrial classification scheme. Strategic materials for defense production can generally be divided into three categories: metals, ceramics, and polymers. These three categories can be combined to create advanced composites and laminates, which are also critical to defense products. Some consider strategic materials to include Petroleum, Oils, and Lubricants (POL); however, governmental mechanisms for handling POL policy are substantially different from these three categories of strategic materials and are generally handled outside of defense channels. Therefore, we have excluded POL from this study.

Within the North American Industry Classification System (NAICS), each of the main material categories has its own Industry Grouping: *Metal Ore Mining* and *Nonferrous Metal Production & Processing* for specialty metals, *Clay Product and Refractories Manufacturing* for ceramics, and *Resin, Synthetic Rubber, and Artificial Synthetic Fiber Manufacturing* for polymers. However, an industry study focused on only one of these groupings would not provide a comprehensive view of strategic materials. Therefore, this study has adopted a “directed telescope” approach whereby a single defense-related industry that makes extensive use of all categories of strategic materials has been selected in order to better assess the associated issues. Correspondingly, this study will focus on *light armor*.

In addition to serving as an instructive case study given its extensive use of all strategic material categories, no industry is more timely and critical to on-going U.S. operations than one directly responsible for protecting combat forces in harm’s way. With the battlefields in Iraq and Afghanistan stimulating demand for body armor for ground troops and appliqué armor for tactical vehicles and helicopters, firms specializing in light armor solutions are flourishing. Moreover, the drive to keep up with the evolving threat of roadside bombs is causing these

companies to make heavier use of advanced and exotic materials. The light armor industry is therefore of critical importance to DOD and serves to highlight key industrial issues, capacity shortcomings, and governmental policy constraints endemic to the strategic materials field.

Current Conditions: The Light Armor Industry

The Industry and Its Value Chain

While the light armor industry is still too much of a niche to be broken out under NAICS, it nevertheless constitutes a viable and thriving market, boosted economically by war demands and energized technologically by emerging battlefield threats. The nature of combat in Iraq and Afghanistan, where there are no front lines or rear echelons, has forced the services to procure light armor solutions in unprecedented numbers and varieties where there was previously no requirement. For the purposes of this study, we define light armor as add-on protective systems for personnel, light vehicles, and aircraft which are not integral to the structure of the item being protected and which may not necessarily be produced or installed by the protected item's original equipment manufacturer. Thus, we do not examine tanks or Armored Fighting Vehicles whose complex (and classified) armor systems are built into their structures at the factory.

All light armor solutions make use of metals, ceramics, and polymers (typically in fiber form) either in unitary construction or, more often, by combining them into composite or laminate systems. Body armor is the most basic example of a light armor system. The state-of-the-art Interceptor Body Armor system combines an Outer Tactical Vest of multi-layered aramid fiber for blast and fragment protection with a set of Small Arms Protective Insert (SAPI) plates made of ceramic (with a laminated fiber backing) for impact and penetration resistance. Add-on armor kits for aircraft tend to use a similar system of ceramic plates combined with ballistic fiber. In both cases, weight is at a premium, which drives the selection of these more exotic and higher cost materials. In addition, each component of these armor systems has an extensive value chain.

Ceramics have a complex value chain consisting of raw ore extraction, powder production and refinement, molding and sintering, and the application of other materials such as fiber backing. Each of these steps is often performed by a separate firm; while some firms may cover several steps, none has the entire value chain in-house. Fiber-based armor systems may be comprised of stand-alone flexible fabrics or a combination of fibers with a polymer matrix (resin) to form structural composites. In any fiber-based solution, fiber selection is not the only engineering variable. Ballistic performance can be tailored by carefully selecting the method used to weave the fibers into fabric, the pre-impregnation of fabrics with certain chemicals, and the selection of the resin matrix material and method of curing. Each of these techniques constitutes a step in the value chain and, as with ceramics; no single firm encompasses the entire chain.

In spite of the weight advantages of ceramic and fiber-composite solutions, light armor for vehicles favors heavier but less-costly metallic systems since weight is at less of a premium. Metallic armor, although not a new technology, “continues to exhibit properties that cannot be matched by other materials: cost, fabricability, durability, multi-hit capacity, and a broad-threat spectrum resistance” (Montgomery, 2004, p.20). Most appliqué armor systems for vehicles are some variety of steel and/or aluminum with a complex value chain consisting of

ore mining, smelting and refinement, alloying and milling, and final cutting and shaping. Although these commonplace metals are not necessarily *strategic materials* by definition, the specific alloys used for armor are highly specialized and not commodity items. True specialty metals, particularly titanium, have significant potential to exceed the performance of the more common metals; however, high cost and periodic availability issues have hindered widespread application in light armor systems to date. This may change as capacity grows and/or lower-cost production methods begin to mature.

Companies that produce body armor and outfit vehicles and aircraft with armor kits comprise the light armor industry. Not all of the companies this study examines would consider themselves as dedicated armor companies, but many do. Several of the largest, such as Armor Holdings Inc. and Force Protection Inc., consider themselves as full-spectrum armored solutions providers and are horizontally integrated to provide metallic, ceramic, and fiber systems even though they may not produce any of the component materials in-house. Other firms, such as Ceradyne Inc. or NP Aerospace Ltd., confine themselves to those types of armor systems that fit their core competencies (ceramics and advanced composites, respectively). These firms often integrate vertically to produce their own subcomponents and intermediate materials. Unfortunately, no armor firm ever fully integrates to the point of controlling the extreme left of the value chain: raw materials. Raw materials are typically commodity items sourced overseas due to the location of mineral deposits and prevailing environmental regulations. Thus, while the government can closely track the domestic content and supplier base for intermediate and finished armor products, the origin of the ores, minerals, and chemical base stocks that comprise these vital materials is often obscured.

Whatever their chosen business model, firms that deal in light armor solutions are competing fiercely for tens of billions of dollars in war-related orders as well as two even greater prizes. The first of these is the inevitable post-war reset of U.S. ground force equipment that will require the refurbishment or replacement of virtually all vehicles. The second prize is the Army's Future Combat System, which is centered on a new generation of lightweight fighting vehicles using modular armor packages employing light armor technologies. Having defined strategic materials and described the scope and character of the light armor market upon which this study will focus, we turn our attention to a more detailed market analysis and an exploration of the challenges faced by the industry.

Light Armor Market Analysis

Market Structure. Combat operations in Afghanistan and Iraq have highlighted the need for armor and advanced materials solutions and created a significant market for light armor. Like strategic materials, however, the armor market and supporting commodity markets do not easily fit in any one industry. Morningstar, Yahoo Finance, and other financial agencies categorize many of the leading armor firms into different industries and sectors. For example, firms such as Ceradyne, Inc. and European Aeronautic Defense and Space Company (EADS) fall into the "Industrial Goods" sector while Titanium Metals Corporation (TIMET) and DuPont are in the "Basic Materials" sector (YAHOO! Finance, n.d.). To complicate further its market identity, there is no single industrial classification for firms producing armor products, components or subcomponents. Such firms span multiple industries including textiles (Polymers Group), metal products (The Allied Defense Group), diversified (3M), and

especially Aerospace & Defense (Saint-Gobain) (Morningstar.com, n.d.). Although armor-producing firms belong to no single industry or sector, armor is definitely a market.

There are two primary groups of customers competing for the purchase of armor: the government (federal, state and local) and the civilian sector (protection and security agencies, paramilitary organizations and private citizens). These buyers compete for products, raw materials and resources from sellers and thus define the market (Gwartney, Stroup, Sobel & MacPherson, 2006, p. 71). On the supply side, many firms offer a wide array of light armor end items ranging from vests, helmets, and garments to vehicle armoring. These firms include Armor Holdings, Foster-Miller, and Ceradyne. Other firms produce subordinate components such as fibers, composites, specialty metals, crystals, and ceramics. Examples here include NP Aerospace, Saint-Gobain, DuPont, and Ceradyne's Electroschmelzwerk Kempten GmbH (ESK). Several of these firms are vertically integrated with production of both the supporting components and light armor end items. Although firms are expanding their product lines, consumers still require more and better protective armor and materials solutions to meet the changing threat environment. Many firms continue to innovate armor production ranging from military tactical vehicle armor (ArmorWorks) to concealable armor protection for civilians (Point Blank Body Armor, Inc. and PACA Body Armor) (The Manufacturer Webpage, n.d.). The presence of a stable civilian demand and a robust industry of suppliers meeting that demand provides substantial mitigation to supply vulnerabilities that would otherwise occur if the industry responded exclusively to the cyclic demands of the DOD.

The Global War on Terror (GWOT) changes the market structure. Prior to GWOT, the light armor market was strictly a monopsony with multiple producers limited to sales only to government contracts. Today's market has two faces: a free market and a controlled oligopoly market. In the case of civilian sector sales, the dynamic is characteristic of a free market wherein buyers and sellers provide mutual consent to the pricing of items without a government controlled supply-demand. Firms like First Choice Armor and American Body Armor specialize in civilian protection items and operate in this arena. The government operates through purchases and contracts; however, they do so in a controlled oligopoly market wherein the government controls supply and price. There is a small group of firms (Armor Holdings, Force Protection, etc.) supplying armor and advanced materials to the government with moderate to high entry and exit barriers. Specialty metals manufacturers also fall into this market class with only two U.S. producers of titanium sponge, TIMET and Oremet. They sell some 75% of U.S. production to Aerospace & Defense Industry firms. Multiple market barriers to entry and exit do exist. The government restricts foreign and private sales of military specification armor and associated technologies. Specific technical skills, long learning curves, unique manufacturing equipment, economies of scale, high start-up costs, access to patents, and heavy investment in research and development (R&D) also serve as entry and exit barriers for firms. In the civilian market, the standards for protection within civilian and law enforcement agencies, as established by the National Institute of Justice (NIJ), serve as another entry barrier. In spite of these barriers, government and civilian security demands continue to support a thriving market.

Market Conduct. The two distinct customers in the armor market, government and civilian, influence market conduct. Consumers within the civilian armor market compete for products affecting supply and demand. Supply-demand controls then set the price of goods within this market. Price variance derives from product differentiation in terms of armor performance, quality, technology, and quantity. Short-term availability of materials, like

Kevlar® or titanium composites, limits the potential supply of armor. In U.S. manufacturing, production capacity restricts the availability of aramid materials; increased capacity would require capital investments in new facilities. Production restrictions affect pricing policies, buying practices, and the demand for substitute materials. Availability of the advanced materials used in helmets, vehicles and light armor end items also influences the government market. These limitations increase the demand for replacement or alternative solutions to meet contract needs.

Prior to the GWOT, government contracts were consistent in quantity and price, but wartime demands create new dynamics within the market. Urgent and evolving military needs for new armor protection generated surges in quantity and requirements for improved performance leading to short-term adjustments in price and greater competition. In an effort to ensure rapid response and price competition, the government purchased armor and supporting materials from multiple firms within the domestic market, which was/is often contested by foreign production firms. Currently, there is no clear market leader with manufacturers operating near or at capacity. While Armor Holdings and Ceradyne have received the highest dollar value from U.S. government light armor contracts, these firms often purchase ceramic armor products from other manufacturers to meet their obligations. Competition requires maintaining a lean cost structure, managing raw material requirements, improving the quality of products and processes, taking actions to maximize cash flow, strengthening core competencies, and developing new markets. Firms create their competitive reputations in the market through the quality of products and the ability to meet defense ballistic performance specifications and delivery schedules. Some firms confuse restrictions, stringent specifications, controls, and policies with arrogance, but the U.S. government and the NIJ strictly control the armor market to ensure maximum protection and product availability on demand.

Market Performance. In the civilian (free market) and the government (oligopoly with duopsonistic buyers – military and civilian/other governmental security) sectors, the market is performing well. Firms show a balanced strategy of profit-maximization and a sense of ingenuity as they work within the public interest. Price determination within the market continues to reflect competitive forces. These forces support the public interest and drive a customer focus wherein customers realize the best value given urgent need, fluctuating budgets, increasing threats, and large quantity demands. Firms continue to push advancements in science, technology and applied engineering in an effort to produce the most effective protection solutions. Firms also collaborate with government and academia, such as the Center for Composite Materials at the University of Delaware, for research and development to improve threat protection and attempt to accelerate the introduction of new technologies to the marketplace. This is clearly a shared civilian and government interest.

The stability of the market remains a question. Trends are upward but show market spikes in sales and profitability based on current U.S. combat operations and individual firm growth. However, most firms anticipate a drop in federal government purchases after the war. To counter this effect, large firms (Armor Holdings, QinetiQ, etc.) are increasing their share of the civilian armor market and/or diversifying production capabilities. Since the Berry Amendment, Buy American Act, and trade restrictions on armor materials do not affect the civilian armor market as much, light armor production firms have the flexibility to import materials and products to reduce stress on domestic supply or production lines. These firms can compete overseas also, vice limiting sales to the U.S. domestic market. The same is true for firms producing raw materials. U.S. titanium producers fear losing their share in the aerospace

titanium market to foreign firms. For this reason, they are lobbying Congress and the Administration for new legislation or strengthening of existing regulations. Nevertheless, the overall light armor market performance is robust, satisfying both civilian and government customers.

Challenges and Outlook for the Light Armor Industry

In addition to those mentioned above, many geopolitical challenges face the light armor industry. Each brings with it significant implications for U.S. strategic materials policies. This paper will discuss three: globalization, the expanding influence of China, and the impacts of demand instability.

Globalization

Globalization has reshaped the world's industrial base. Notable changes include large-scale consolidation and shifting research and development patterns (Bolin, 2001, p. 13). Weaker competitors have merged with stronger companies or left the market entirely. Over the last two decades, more than seventy-five major U.S. firms merged into just five (Driessnack, 2004, p. 63). Simultaneously, international trade and global competition rapidly expanded as nations sought mutual gains (Gwartney et al., 2006, p. 371). Industries should now consider the global environment when assessing markets. The light armor industry is no exception.

Globalization, and the interdependence of nations and markets that it yields, has affected strategic materials and the light armor industry, as it has every other facet of the international marketplace. Conditions on one side of the globe often have repercussions on the other (Palmer, 2004, p. 9). To compete, companies must now be integrated worldwide (Sullivan, 2002, p. 153). Most international corporations seek linkage to U.S. markets. However, legislation such as the Berry Amendment and the Buy America Act (discussed in more detail later) limit the opportunities available to non-U.S. firms. These restrictions compelled many foreign firms to purchase or build facilities within the U.S. so that their armor-related products could be sold to the U.S. government. Two examples are Saint-Gobain and EADS, both of which established facilities within the U.S. and now sell their products to the U.S. military. These products range from advanced ceramics to specialized fibers and composites. Conversely, U.S. companies such as Armor Holdings, TIMET and Ceradyne have established footholds in international markets by acquiring foreign subsidiaries. This has allowed them to meet the light armor needs of our allies from within their respective countries.

Current trends point toward a continued reliance on a global industrial base to meet U.S. defense needs (On-Site Discussions, 2 May 2007). Such reliance requires an increase in the free exchange of information and technology between U.S. and overseas companies. This exchange of information requires U.S. State Department approval via a Technical Assistance Agreement or Memorandum of Agreement between the companies and/or countries involved (On-site Discussions, 8 May 2007). Nevertheless, domestic economic interests often trump the use of international materials. Globalization has created a conflict in U.S. policy between the desire for U.S. productive capacity and industrial independence versus the cost savings and technology advancements that result from international sources. The conflict can only be answered by determining if we are more secure through independence or through global interdependence.

The China Factor

China's explosive and sustained economic growth has drawn a great deal of attention. Much of that attention focused on fair trade practices and China's geopolitical strength, but an ascendant China's appetite for materials should also be considered. Unless offset by increased production, Chinese consumption of strategic materials could easily inflate global prices, threaten delivery of materials to U.S. manufacturers, and possibly challenge the economic viability of material-dependant U.S. firms.

China has become the world's largest consumer of steel and aluminum, taking in 39% and 30% of world consumption respectively (DUSD(IP), 2005, p. viii). To meet these needs, China has expanded its steel and aluminum capacity resulting in a transition from imports to exports. This has improved DOD's access to U.S.-produced steel and aluminum and stabilized prices of those metals. Titanium is another metal of interest to China. Although China consumes only five percent of the world's supply of titanium today, its demand is growing (DUSD(IP), 2007, p. 6). As China's industry and economy continue to expand, Chinese demand for copper, steel, aluminum, and titanium will likely continue increasing over the next 20 years.

China's demand for high-quality ceramic raw materials is also on the rise. As a result, China has begun to limit its exports in order to satisfy domestic needs (Grahl, 2007, p. 10). Leading U.S. scientists predict that China will make substantial in-roads on important ceramic powders needed for light armor production, powders such as silicon carbide and boron carbide (Scientist, 2007). Such in-roads in other raw materials are already evident as China secures access to materials around the world, recently purchasing firms in at least five African nations for materials such as chrome, gold, iron ore, and copper (Timberg, 2007, p. A 14). The Chinese government has also provided preferential loans to Chinese companies working in Africa and eliminated tariffs on some 200 manufactured goods from Africa (Economist Intelligence Unit, 2006). These global efforts portend fierce competition for commodities of U.S. national interest. Thus, DOD should monitor China's demand, ownership, and production of material.

China's increased vertical integration could have other implications including the possibility of a naval arms race. Should it recognize the strategic vulnerability of unprotected sea lines of communication to transport its raw materials from overseas, China might expand its navy to secure access to foreign minerals. While speculative, such a possibility highlights the need for U.S. policy makers to consider both military and economic risks arising from China's expanding influence. A multi-pronged U.S. policy approach is warranted. Such an approach should focus on (1) close attention to the entire materials supply chain, (2) enhanced focus and flexibility for U.S. strategic material managers (such as the newly legislated Strategic Materials Protection Board and the Defense National Stockpile Center), and (3) legislative adjustments that more deftly balance the benefits of globalization with the protection of U.S. industrial capacity.

Demand Instability and Raw Materials Availability

The Global War on Terrorism has increased demand for strategic materials, which are integral to effective light armor. Expanding asymmetric warfare and insurgents' tactics imposed a surge requirement on a stable market. However, military success or political opposition could end the conflict and the need for armor, as quickly as it arose. This unpredictability continues to

be problematic for the industry causing significant ramp-ups of production and supply inventories throughout the value chain. The magnitude of change precludes industry from projecting demand, aligning suppliers, or making critical capacity investment decisions. Once the war is over and demand stabilizes or decreases, the industry will again struggle to adjust. Demand dynamics are but one factor in material availability, mining and processing is another.

Availability of raw materials is driven less by their abundance in the earth's crust and more by the cost of mining and processing these materials into a usable form. Mining of materials is often labor and energy intensive, and is subject to increasingly stringent environmental controls. Mineral price volatility deters companies from expanding mining or production capacity. Further complicating the picture is mineral interdependence. Minerals such as rhenium are byproducts of the mining of other minerals, in this case copper. Thus, if the demand for copper decreases, the production of rhenium does as well. China's increased consumption, and to a lesser extent the current conflicts in the Middle East and Africa, has increased commodity prices and depressed supply. Nevertheless, industry leaders remain reticent to expand capacity, fearing that China's growth will slow, resulting in excess capacity. Thus, encouraging companies to continue to invest in mining and processing capability requires government policies that create a steady demand. The difficulty for the government is to purchase sufficient quantities of commodities when demand is low to maintain, but not overly stimulate, production while avoiding large, expensive stockpiles of material that may or may not be needed in the future. Effective materials management processes are essential to protect against the strategic risk of material unavailability.

Governmental Factors and their Influence on Strategic Materials

The government's Constitutional roles to provide for the common defense and secure the blessings of liberty have direct implications for strategic materials. Specifically, governmental legislation, policy, and programs substantially affect the domestic materials industry such as the Berry Amendment, specialty metals legislation, the Buy American Act, the Defense Procurement Act Titles I and III, and the National Defense Stockpile Center. Examining these areas shed insights into the interplay of government and industry.

Refining the Berry Amendment, Specialty Metals Legislation, and the Buy American Act

Congress and the DOD have long debated the need to protect the U.S. defense industrial base by restricting certain federal procurements to U.S. markets. The Berry Amendment, enacted in 1941, contains a number of source restrictions that prohibit the DOD from acquiring food, clothing, and fabrics including ballistic fibers, specialty metals, stainless steel, and hand or measuring tools that are not grown or produced in the United States (Grasso, 2006, p. 5). The Fiscal Year 2007 National Defense Authorization Act, enacted on October 17, 2006 (Grasso, 2006, p. 1) removed the specialty metals clause from the Berry Amendment and created a separate statute prohibiting the use of appropriated funds to procure specialty metals critical to national security unless they are reused, reprocessed, or produced in the U.S. The Berry Amendment's tight textile restrictions have significant impact on the light armor industry given the industry's heavy use of textiles for body armor systems.

Congress and manufacturing associations in the U.S. strongly believe national security is dependent on a strong U.S. industrial base and dependence on foreign sources for critical materials is a risky strategy. Some domestic and foreign companies have also criticized the

Berry Amendment asserting that it undercuts free market competition, promotes discriminatory practices, robs businesses of incentives to modernize, causes inefficiency in some industries due to a lack of competition, and results in higher costs to DOD because the military services pay more for “protected” products than the market requires. Some critics of the Berry Amendment also argue that the U.S. will lose its technological edge in the absence of competition and will alienate foreign trading partners, thereby provoking retaliation and the loss of foreign sales. They assert that the Berry Amendment will ultimately reduce the ability of the U.S. to negotiate and persuade its allies to sell, or not sell, to developing countries. These critics contend that the Berry Amendment promotes U.S. trade policies that undermine international trade agreements (Grasso, 2006, p. 15).

The Buy American Act is a different domestic preference law requiring items be manufactured in the United States and that greater than 50% of the component cost of any item be of domestic origin (Grasso, 2006, p. 6). Under Berry, the restricted items must be 100% domestic in origin. The government should address this inconsistency and consider adjustments to the legislation and its associated compliance issues. First, the burden of proof should be shifted to those most able to assess compliance, rather than either the government or the end-product manufacturer. The material supplier (the weaver and fiber manufacturer for example) should have the primary compliance task, coupled with a government-designed system to support tracking. In fact, the government and industry should be able to verify compliance throughout the entire value chain. Second, the differences between the Buy American Act, the Berry Amendment, and the Specialty Metals legislation need to be reconciled. The web of requirements creates undue burden and complication on both the government and industry and limits the desirability of U.S. products in international markets. Most importantly, the tailoring of restrictions within the Berry Amendment to allow more expeditious waiver processing and less stringent restrictions, reaching to the farthest end of the value chain is critical, especially for life-saving items such as armor protection. The inability to get armor to our service members in a timely fashion due to government regulation is unacceptable.

Defense Production Act (Titles I and III)

The Defense Production Act (DPA) is a unique authorization that allows for direct domestic industry intervention when needed for national security. Within the current act, Title I specifically “authorizes the priority of certain government contracts ahead of other contracts and allocation of designated scarce critical materials” (Ruane, 2002, p. 34) for national defense and homeland security priorities. Title I authority has been used extensively in the current Global War on Terror to provide fibers for body armor production and even to expedite repair of machinery used to manufacture ballistic steel plate for vehicle armor (DUSD(IP), 2006 & 2007, pp. 43, 84 & Patrick, 2003, p. 4). However, government use of the DPA Title I authority can create issues for affected firms when non-defense customers move to other sources rather than wait in line behind defense needs. Judicious use of the authority is important to maintain a free market.

DPA Title III “authorizes the President to use financial incentives” (Ruane, 2002, p. 47) to “create, expand, maintain, or modernize” (Buefler, interview, 2007) U.S. industrial capacity. The Title III program seeks to lower acquisition and sustainment costs while improving production in critical areas where industry may not find development to be cost effective

without government assistance (Advanced Systems and Concepts, 2005, p. 13). The act has assisted government researchers, program managers, and industry in bridging the “valley of death” to get technological breakthroughs into production for defense use (Mirsky, 2005, p. 2) and can advance technology to production by four to six years (Buffler, interview, 2007). The use of Title III in the past addressed strategic material areas and was a driver in the establishment of the manganese (Ruane, 2002, p. 23), titanium, and aluminum industries (Mirsky, 2005, p. 1).

Concern for a U.S. industrial capability sufficient to meet current and future asymmetric conflicts has helped reinvigorate support for the DPA program. A strong strategic communications plan and expanded use of this vital authority should be a DOD imperative to ensure our confirmed status as a world power.

Reinvigorating the National Defense Stockpile

The United States has maintained a strategic material stockpile for over half a century. There are currently 68 commodities in the Defense National Stockpile Center (DNSC). Harvard professor and economic warfare expert William Y. Elliott noted in an unpublished 1945 paper that “no private corporation could afford to make the costly investment in materials ... which were absolutely essential if we were to be relatively well protected against the loss of sources of these supplies” (DeYoung, et al., 2006, p. 488). This captures the essence of the argument for a national stockpile.

Perception of the stockpile’s importance has waxed and waned, rising during periods of geopolitical tension, falling during times of relative calm. In 1992, shortly after the end of the Cold War, Congress directed the DNSC to liquidate its inventories. Paradoxically, as stockpiles dissipate, U.S. defense needs for strategic materials grow more acute. These materials, and composites thereof, offer the superior temperature tolerance, lower weight, and greater tensile strength crucial to DOD’s quest for lighter and stronger armor, improved performance, greater fuel-efficiency, and reduced maintenance cost. Defense platforms using specialty metals include the Apache helicopter, Joint Strike Fighter, F/A-18E/F fighter, Stryker vehicle, Delta II rocket, and the workhorse HMMWV, not to mention less glamorous applications such as fuel cells, armor, and naval propulsion and power generation.

Without the DNSC, the U.S. will instead rely on competitive international markets. Strategic materials sources are limited as are domestic production capabilities for many critical materials, including titanium. Some material sources are based in countries with which the U.S. has uneven relations such as Kazakhstan or Russia, and fierce competition for these materials looms as the needs of China and India swell. Each of these situations raises the specter of an interruption of strategic material supplies. This could pose a vulnerability to material access and a threat to U.S. national security.

Establishing a stable, agile national stockpile of materials mitigates the threat to national security. This would guarantee access to those elements, allowing the U.S. to purchase them at favorable rates and at times of its choosing, and enable movement of materials into and out of the stockpile to meet the needs of the U.S. defense industry. A more frequent examination of the stockpile list should ensure that the proper materials in the proper form are adequate to satisfy national security needs. The current study directed by Congress to review future stockpile requirements is a very positive step, the results of which should help inform the new Strategic Materials Protection Board’s decisions.

Restrictions on Technology Sharing

Export controls and the International Traffic in Arms Regulations protect and restrict U.S. technological advances from entering enemy hands. These controls also affect the light armor industry. Firms are restricted in the transfer of critical technology to other nations, which is difficult to monitor, especially in the age of globalization and international mergers. While clearly in the interest of U.S. national security, these restrictions make it difficult to share leading edge technology and manufacturing techniques that could provide better protection for military members serving in hazardous environments by building additional and capable production capacity internationally at all levels in the value chain. The lengthy timeframes to process licenses and review waivers further restricts the flexibility of industry to meet the demand. However, at the price of burdening industry and losing some benefits from globalization in cost and material availability, these restrictions are necessary.

With some adjustments, all of these government interventions can have complementary effects throughout the light armor industry. With some reconciliation, the Berry Amendment and the Buy American Act can better promote U.S. domestic material capability. DPA Title I and III currently provide effective alternatives to help industry sustain or develop production capacity. A reinvigorated materials stockpiling program can prevent shortages and offset risks driven by vulnerable sources of supply. The newly legislated Strategic Materials Protection Board can begin to address comprehensively the security aspects of materials (albeit more so by including interagency and industrial representation). In fact, the establishment of this Board provides an excellent opportunity to assess global strategic materials and manage the associated material issues to mitigate U.S. national security risks.

Essays: The Essential Truths of Light Armor Materials

Light armor systems are dependent on constituent materials and the combination of these materials into composites. While all of these constituent materials serve the light armor industry, their application and dynamics are much more expansive. The following essays serve to reveal essential truths about these materials as they affect light armor and other industries.

Composites

Background. Composite materials (or composites) are engineering materials made from two or more different materials. The different component materials have unique and dissimilar physical or chemical properties that remain separate and distinct at the macroscopic level within the resulting constructed material. However, these components integrate to form a new material with its own unique physical and/or chemical properties. The integrated material produces properties unavailable from the individual component materials.

Overall, the benefits of composites lie in their lightweight, high specific strength and stiffness, corrosion reduction, property tailoring, and increased flexibility of design. Potential areas ripe for exploitation include reduced radar signature and electromagnetic shielding (Potter, 2003, pp. 38-39). In view of the changing threat environment facing the DOD, these

benefits are of greater interest each day. Today, aircraft, ships and land vehicles use composites for structural material as well as for ballistic protection.

Composites in Aviation. Advances in composite technology have also resulted in revolutionary changes within the world of aeronautics. Today's aircraft are no longer manufactured from metals and metal alloys exclusively. Instead, they increasingly use advanced composite materials to reduce part counts, produce complex geometries, decrease overall aircraft weight, and improve stealth. Both U.S. and European aircraft manufacturers have incorporated this technology into their most advanced fighter aircraft. These systems include the F-22 Raptor, the Joint Strike Fighter, and the Eurofighter.

In addition, the use of composite technology in the aircraft market is not limited to just military systems. According to several industry officials, advanced composite materials and technology have also begun to infiltrate the commercial aircraft sector. For example, Boeing has designed the fuselage of its new 787 Dreamliner™ completely of composite materials, a first for the commercial aircraft industry (Boeing Website, n.d., ¶1). Other examples of the widespread application of composites in commercial aircraft include the Airbus 380 and EADS' helicopter business. The future growth of composites in aircraft and helicopters will rely on the industry's ability to reduce the costs associated with their manufacture (On-Site Discussions, 9 May 2007).

Composites in the Maritime Arena. In the maritime arena, recreational vessels currently dominate the use of composite materials with very little application in the naval services. However, this trend is shifting due to the changing threat environment and mission profile facing the world's naval forces. It is projected that naval vessels will operate far more frequently in the littoral regions than conducting operations in the open ocean. The large degree of low-tech weapon proliferation in the littoral regions makes naval vessels more vulnerable and accordingly increases their survivability requirements (Ashe, 2006, p. 219).

To counter these projected threats, Sweden and Norway are developing and building naval ships with hulls and superstructures constructed fully from composite materials, the Swedish VISBY corvette class and the Norwegian SKJOLD Missile Torpedo Boat class of vessels. In each case, composites enable reduced vessel displacement and enhanced stealth (Crane, Gillespie, Heider, Yarlagadda & Advani, 2003, p.41). In the United States Navy, composite utilization is limited to superstructure components such as the Advanced Enclosed Mast/Sensor (AEM/S) system for the SAN ANTONIO class of amphibious vessels (Naval Technology web site, n.d., ¶13) and the projected superstructure of the ZUMWALT class of DDX destroyers (Naval Technology web site, n.d., ¶9). The level of composite utilization within the United States Navy will increase as the production technology matures and the ability of integrating the composite's functionality into a repeatable and affordable manufacturing process improves (Crane et al, 2003, pp. 42 & 44).

Composites and Land Vehicles. To date, the racing and sports car industry dominates the composite field in land vehicles. However, with the changing urban threat facing military forces around the world, the trend is slowly beginning to change. Currently, the United Kingdom is testing and evaluating an all-composite hull armored fighting vehicle (Jane's, n.d., ¶1). A composite hull offers significant advantages over conventional aluminum and steel hulls including a reduction in weight, decreased acoustic signature and the incorporation of stealth characteristics, and thus increased battlefield survivability and system maintainability (Jane's, n.d., ¶2).

High Performance Fiber Materials

Background. Modern fiber materials are meeting the advanced needs that natural materials can no longer satisfy. Fiber materials used in fabrics and clothing are a prime example. Fibers can be woven into reinforced fabrics to form a composite that not only provides protection but also saves lives. As with all composites, the individual fiber materials retain their unique identities while acting in concert with each other. An early fiber composite still widely used in production today is fiberglass.

As a fiber, glass is strong and flexible. These attributes make fiberglass an attractive composite, but a more compelling reason for its continued popularity is that fiberglass is relatively inexpensive. The same properties that make fiberglass attractive also influence the development and use of other fiber composite materials. Fiber composite materials are manufactured to be stronger and lighter than their metal counterparts and have the added benefit of corrosion resistance. These advanced fiber materials are less common in everyday usage because they are expensive. High performance fiber composite materials in use today are carbon fibers, aramid fibers, and ultra-high molecular weight polyethylenes.

High performance fiber materials are manufactured through a process called spinning. This process extrudes a polymer (polyacrylonitrile) through the tiny holes of a device called a spinneret to form continuous filaments of semi-solid polymer (Fibersource website, n.d., ¶13). Manufacturers use unique polymers that differentiate the product line they deliver. The extruding process pulls the molecular chains of the polymer together and orients them along the fiber axis creating a considerably stronger fiber (Fibersource website, n.d., ¶14). To produce carbon fiber material, the filaments are then superheated to develop carbonized fiber. Laboratories such as the Army Research Laboratories at Aberdeen Proving Grounds continue researching new combinations and methods to produce composites that are stronger, lighter, and better able to serve the defense industry. Carbon fibers have revolutionized personal protection but are not the only fiber material on the market, another is aramid.

Aramid fiber materials derive their name from shorthand for the scientific name *aromatic polyamide*. Common aramid and para-aramid products are more widely known by their brand names of Kevlar® and Twaron®. DuPont introduced Kevlar® as a brand name in 1965. Each of these fiber materials have a rigid molecular structure with varying properties that provide bullet and stab resistance as well as protection against thermal hazards, depending on the weave of the filaments and final finish of the cloth. DuPont boasts Kevlar's performance to be five times stronger than steel on an equal weight basis, while still lightweight, flexible and comfortable. Alternatives to aramids include ultra-high molecular weight polyethylene fiber products marketed under brand names such as Spectra Shield® and Dyneema®. One may note that body armor end items such as the vests do not bear these product names. This is because in the value chain of production, the high performance fiber products are components produced early in the chain.

Carbon fiber materials and aramid material composites appeal to the DOD because their incredible strength and light weight make them ideal substitutes for traditional metallic armor. The standard HMMWV used today in Iraq and Afghanistan has been up-armored to make it a survivable platform. The additional armor load has taken its toll on the HMMWV suspension.

It is clear the DOD needs to develop composite armor to reduce the overall weight of the vehicle. Fiber composites can meet this need both on tactical vehicles and on the soldier.

The High Performance Fiber Material Market. As noted above, there are several firms in the global high performance fibers market. The health of the industry is solid with ample demand for these materials from both the government and civilian sectors. While the government has placed a significant demand on the fiber industry for materials to manufacture personal protection items such as body armor vests and related items, the DOD is still just a fraction of the overall fibers market that supports everything from aircraft to golf clubs. Today, commercial market demand has expanded to such an extent that the DOD accounts for less than ten percent of the domestic market and less than five percent of the world market (Committee, 2004, p. vii). The increase of non-defense demand for the same materials used in commercial applications such as aircraft makes the DOD a less influential customer. A decreased market influence coupled with the burdens of legislative restrictions such as the Buy American Act and the Berry Amendment make the DOD a less attractive customer for fiber industry suppliers. The relative decline in percentage of defense demand for composites relative to commercial demand has important implications for future access to affordable fibers able to meet DOD specifications.

Recommendations for the Fiber Industry. To counterbalance the downside of relatively small government purchase quantities, high performance requirements, cyclic demand, reprioritization authority, and strict legislative compliance issues, the U.S. government needs to make long-term commitments to domestic fiber materials suppliers. This will mitigate the cyclic defense demand that complicates industry capital investment decisions and will reinforce the government's position as a valued customer of high performance fibers. Additionally, continued government activity in fiber research and development (R&D) will secure access to fibers meeting defense needs. The aim of these R&D efforts should be on producing more efficient processes that will lessen the cost of the materials to the degree they are a viable replacement for soldier personal protection and vehicle armor systems.

Ceramics

Background. Silicon Carbide (SiC), Boron Carbide (B₄C), Alumina (Al₂O₃), and a specific form of alumina, known as Sapphire or transparent alumina, are currently the ceramic materials of choice for armor applications. While ceramics offer excellent ballistic properties at lighter weights than other materials, barriers to their use are their relatively high cost as compared to other armor materials; inconsistent, batch-driven manufacturing processes; and raw material inconsistency and availability. Combined with a soft material backing for body armor, a hard backing for vehicle armor, or a polycarbonate/acrylic laminate for transparent armor, the ceramic absorbs the "ballistic impulse" of a projectile by eroding the projectile and/or dispersing the projectile's energy (Normandia, M.J., LaSalvia, J.C., Gooch, W.A., McCauley, J.W., & Rajendran, A.M., 2004, p. 22).

The Ceramic Armor Market. While the U.S. domestic armor-manufacturing base is currently financially sound, acquisitions and the current robust DOD spending under the Buy American Act are major factors in their current success. U.S. ceramic production, and particularly ceramic powder production, is in overall decline relative to the rest of the world due to rising energy costs and stricter environmental controls. World mineral reserves are more than adequate for the foreseeable future to synthesize ceramic armor materials; however,

increasing reliance on foreign sources of ceramic powders used in ceramic armor production is unlikely to change in the near future without addressing energy and environmental challenges.

Unlike the continuous production processes of metals and polymers, ceramic production is a batch process. Because any change in the raw material or process between batches can lead to inconsistent products, ceramic manufacturers are particularly vulnerable to changes in their raw materials (Zamek, J., 2007, pp. 26-31). Thus, the primary strategy employed by ceramic armor manufacturers is one of vertical integration on a global basis. The starting minerals such as silica, boron, and bauxite are mined from the earth, but synthesis of these minerals to boron carbide and alumina powders requires tight process controls to reduce impurities. Production of the powders is energy intensive and produces toxic byproducts, which limit production locations. In 2004, Ceradyne acquired ESK ceramics, a German company, which refines silicon carbide powder for armor sold primarily in the U.S. ESK, however, must obtain its raw silicon carbide on the world commodities market. ESK does produce boron carbide for body armor, which is particularly beneficial for Ceradyne Inc. Armor Holdings is an exception, having acquired Simula, Inc. to vertically integrate a ceramic armor supplier for their larger business, composite armor manufacture, rather than acquiring a ceramic powder producer.

The dichotomy facing U.S. ceramic armor manufacturers is the political support for ceramic armor manufacture without the environmental and energy support for ceramic powder production. Recently the New York Power Authority trustees approved an allocation of Niagara Falls low-cost hydropower to support the manufacture by Saint-Gobain Ceramics of various ceramic products including armor materials. At the same time, a lapsed air permit for the former SGL Carbon plant in New York thwarted plans for starting up silicon carbide production.

In spite of ceramic armor manufacturing challenges, the current conflicts in Iraq and Afghanistan ensure there will be a requirement to produce armor products for the foreseeable future. The industry can expect to continue at its current pace of production for the next year or two to support the on-going conflicts and to recapitalize U.S. and allied military equipment. The technological advances gained through current research will transfer to commercial ventures such as law enforcement, the private security industry, and even non-governmental organizations serving in conflict zones. The more diversified the company, the less susceptible to radical shifts in demand, and the more likely the company will survive outside the military niche market.

Titanium

Background. Titanium (Ti) is relatively young in metallurgical history. Discovered by William Gregor in 1791 and named by Martin Heinrich Klaproth in 1795, the properties of titanium were not identified until 1887 when Nilson and Pettersson produced an approximately 95% pure concentration of the metal. In 1910, an American chemist, M. A. Hunter, produced a 99.9% pure concentration when he heated titanium tetrachloride (TiCl_4) with sodium in a steel kiln. Mainly used in laboratory research until 1946 when W.J. Kroll first produced titanium commercially through the reduction of TiCl_4 with magnesium. This process remains the most common means of producing the metal today. With a commercially viable production process, titanium utilization steadily increased.

Titanium exists primarily in the minerals anatase, brookite, ilmenite, perovskite, rutile, titanite (sphene), as well in many iron ores. Of these minerals, only rutile (titanium dioxide) and ilmenite (iron-titanium oxide) have any economic importance. Unfortunately, high concentrations of the mineral types most easily processed into metal form are difficult to locate. Significant titanium-bearing ilmenite deposits exist in Western Australia, Canada, New Zealand, Norway, and Ukraine. Large quantities of rutile are also mined in North America and South Africa. Total known reserves of titanium raw materials (anatase, ilmenite, and rutile) are estimated at over 2 billion tons (U.S.G.S., 2007, p. 175).

Due to its tendency to react with air at high temperatures, titanium cannot be produced by reduction of its dioxide. The commercial extraction (Kroll process) involves treatment of the ore with chlorine gas to produce $TiCl_4$, which is then purified and reduced to its metallic form by reaction with magnesium or sodium. As the metal forms, it has a porous appearance and is referred to as *sponge*. The sponge is blended with alloying elements as desired and then vacuum melted. Several meltings may be necessary to achieve a homogeneous ingot that is ready for processing into useful shapes, typically by forging followed by rolling. During the melting process, titanium sponge can be combined with scrap to optimize material usage. The difficulty in processing titanium makes it relatively expensive in comparison with steel or aluminum. Nevertheless, the exclusive properties of titanium, such as superior strength-to-weight ratio, excellent corrosion resistance, superior erosion resistance, and high heat transfer efficiency (relatively high melting point of over 1,649 degrees C or 3,000 degrees F) continue to drive global titanium demand in aerospace and military uses.

The Titanium Market. There are two primary forms of titanium used in industry, titanium dioxide and titanium metal. Titanium dioxide (TiO_2) is a brilliant white pigment used in paint, paper, rubber and plastics. While light armor focuses on titanium metals, it is important to understand that 96% of the domestic consumption of titanium mineral concentrates in 2005 went to the production of TiO_2 pigment. Only about five percent of titanium mineral concentrates in 2006 were used to produce titanium metal, welding rod coatings, and fluxes. U.S. producers of titanium metal are TIMET, ATI (Allegheny Technologies Inc.), Wah Chang, RTI International Metals Titanium Group, Honeywell Electronic Materials (a subsidiary of Honeywell International Inc. and parent firm of The Alta Group).

U.S. imports of titanium metal are primarily in the form of unwrought titanium. Kazakhstan (53%), Japan (39%), and Russia (6%) were the leading sources of imported titanium sponge, while Japan (24%), France (17%), the United Kingdom (17%), and Germany (13%) were the leading sources of imported waste and scrap. The leading import sources of titanium ingot were Russia (78%) and Germany (14%). Imports of titanium powder were 126 tons, an 11% decrease compared with those of 2004. China (68%) was the major source of titanium powder. Imports of other unwrought forms of titanium increased by 39% compared with those of 2004. (U.S.G.S., 2005, p. 78.4).

During the next several years, titanium metal producers from around the globe will be increasing titanium sponge capacity significantly through the expansion of existing facilities in China, Japan, and Russia and the addition of new operations in China and the United States. Numerous government and private industry programs are working to commercialize lower cost methods for producing titanium metal. At least one of these methods should reach commercialization within the next two to three years. By 2008, domestic and global sponge capacities are predicted to reach 31,000 tons per year and 142,000 tons per year, respectively.

Growth in commercial aircraft and defense applications are expected to drive demand for titanium metal over the long term (U.S.G.S., 2005, p.78.6).

Titanium metal and its alloys have proven to be technically superior and cost-effective materials of construction for a wide variety of aerospace, industrial, marine and commercial applications. In the U.S., the aerospace industry uses approximately 75% of the titanium metal consumed and is the primary market driver. However, the automotive industry is projected to expand its use of titanium in the next few years, which could further stress supply and create additional increases in titanium metal prices unless offset by increased global supply. Due to the importance of titanium and its alloys for the U.S. aerospace (jet engine and airframe components) and military (high strength, low weight applications and armor) applications, titanium can certainly be considered a strategic material.

Nanotechnology

Nanotechnology is the new buzzword in the study of materials science. It is the ability to understand and take advantage of material properties at the microscopic level. As the light armor industry continues to search for lighter and more cost effective solutions, one option to assist in this quest is the exploitation of nanotechnology. Broadly speaking, nanotechnology is the synthesis and application of ideas from science and engineering toward the understanding and production of novel materials and devices. This technology allows tiny building blocks to be manipulated into materials, shaped by directed or natural self-assembly. One application is a nanocoating to clothing that allows the cloth to be water-repellant or electro-conductive. Another application is the ability to enhance night vision through nightglow and the exploitation of nanocrystals. Nanotechnology is a wide-open field with potential for a multitude of end products that can enhance national security.

Materials reduced to the nanoscale suddenly show very different properties compared to the macroscale, enabling unique applications. For instance, opaque substances become transparent (copper), inert materials become catalysts (platinum), stable materials turn combustible (aluminum), solids turn into liquids at room temperature (gold), and insulators become conductors (silicon). Materials such as gold, which is chemically inert at normal scales, can serve as a potent chemical catalyst at nanoscales. Much of the fascination with nanotechnology stems from these unique quantum and surface phenomena that matter exhibits at the nanoscale.

Nanotechnology offers properties like greater mechanical strength, heat resistance, and superconductivity. Nanoparticles are of great scientific interest as they are a bridge between bulk materials and atomic or molecular structures. A bulk material should have constant physical properties regardless of its size, but this is often not the case at the nanoscale. Nanoparticles exhibit a number of special properties relative to bulk material. For example, the bending of bulk copper (wire, ribbon, etc.) occurs with movement of copper atoms/clusters at about the 50 nanometer (nm) scale. Copper nanoparticles smaller than 50 nm are considered super hard materials that do not exhibit the same malleability and ductility as bulk copper. The change in properties is not always desirable. Ferroelectric materials smaller than 10 nm can switch their magnetization direction using room temperature thermal energy thus making them useless for memory storage. Nanoparticles often have unexpected visible properties because they are small enough to confine their electrons and produce quantum effects. For example, gold nanoparticles appear deep red to black in solution.

The future of nanotechnology has considerable promise. There is a great deal of research and development on-going in both industry and university settings to fully understand the advantages and capabilities. Continued research is important, but must be balanced within the entire research portfolio. Nanomaterials can contribute to enhancements in light armor systems and will help contribute to the military transformation of the 21st century if we can accelerate the transition of materials from concept to use.

Orchestrating Materials Research and Development

In Fiscal Year 2006, the DOD spent approximately \$71 billion on research and development (R&D) (White House, 2006, p.6). This represents approximately 15% of the total DOD budget for the year. The DOD has shown their commitment to R&D by keeping this annual percentage fairly stable over time. Department of Defense Directive 5134.3 gives DOD Research and Engineering (R&E) the responsibility for “recommend[ing] ... appropriate funding levels for R&E” and “oversee[ing] matters associated with R&E at DOD laboratories operated by the military departments or other DOD components.” This is a powerful and very important role for DOD R&E to guide the U.S. into the next century as an international technology leader.

Based on observations at numerous government, industry and university laboratories, it is clear that collaboration is critical to the U.S.’s ability to maintain technical supremacy in the world. In addition, the DOD needs to play a key role in ensuring that U.S. scientists and engineers are educated and developed to engage in the future national security environment.

The government does encourage collaboration. An example of this collaboration is a study conducted by the National Research Council (1999) that investigated materials research and development needs for the 21st century (National Research Council, 2003). Results of the study listed five classes of research needs based on revolutionary defense capabilities required for the next century. The areas include structural and multifunctional materials, energy and power materials, electronic and photonic materials, functional organic and hybrid materials, and bio-derived and bio-inspired materials. These categories and warfighter needs should facilitate collaboration among DOD scientists and engineers and drive research priorities.

Other efforts that encourage collaboration include conferences, private and government publications, and many contract mechanisms that encourage agencies to get involved in government research. The government must encourage many more incentives to collaboration. For instance, government researchers should be incentivized for the number of publications per year on which they collaborate with university or industry partners. In addition, the DOD should make it mandatory for all R&D programs to have an industry and university partner. Efforts to encourage collaboration amongst the government, industry and universities will certainly increase the technology gains of the DOD and the private sector. Efforts to collaborate will also allow more research dollars to be spent on a variety of different fields. The current lack of collaboration in the laboratories leads to frequent duplication of effort. Some duplication should be encouraged in order to gain better technological advances but excessive duplication wastes taxpayer dollars.

In addition to encouraging collaboration, the DOD has a key role to play in ensuring the education and training of our next generation of scientist and engineer. Virtually every respected organization in business, research, and education as well as government has documented the critical shortcomings of science, technology, engineering, and mathematics

(STEM) education in the U.S. (Association of American Universities, 2006, p. 15, National Academies of Science, 2005, p.20). The DOD should continue to offer scholarships to young students who are interested in studying STEM in college. These students would then begin to satisfy the continuing need for scientists and engineers in DOD laboratories.

The future of defense-related R&D continues to be bright. The DOD has always been willing to invest in the future to ensure warfighters have the maximum combat advantage possible. In this century and the next, collaboration and scientist and engineer development will be key to continued U.S. national security in a dynamic international environment.

Summary of Recommendations to Mitigate “Strategic Materials” Risks

In a perfect world, the U.S. industrial base would consist of numerous suppliers at all levels in the supply chain competing for an equally robust defense and commercial market. The DOD and other national security agencies would have reliable access to leading edge technologies that would be quickly and affordably transitioned into combat capabilities when needed. This world does not exist. Therefore, careful attention should be paid by the U.S. government on the vitality of its industrial base and associated strategic materials.

As this study’s analysis of the light armor industry has highlighted, there are several actions that can be taken to mitigate the national security risks associated with strategic materials; specifically, the U.S. government should

- *Revisit the processes used to assess and manage global strategic materials to include a revitalization of the national defense stockpile center.* Government should improve its interaction with industry to mitigate the supply side vulnerabilities of strategic materials and should better coordinate across government agencies to manage materials risks. The defense stockpile should transition to a more agile and active component of a more proactive strategic materials management process.
- *Conduct a comprehensive and systematic assessment of the global value chain supporting U.S. defense requirements.* The U.S. government should proactively examine strategic materials along the entire defense portfolio value chain to understand domestic and international market dynamics and take pre-emptive action when the interests of national security are at risk. These first two recommendations are ideally suited to the newly minted Strategic Materials Protection Board.
- *Improve the integration and coordination of research and education among government, industry, and academia to generate synergy in technology development.* This includes improving support to industry through government/industry partnerships to speed the development of efficient production capabilities for new technology and thereby bridging the gap between new technology and fielded systems.
- *Harmonize the various pieces of legislation that address strategic materials.* This effort should reassess the effectiveness of current statutory constraints, improve regulatory consistency, ease the burdens of compliance on industry, and minimize interference with free market dynamics in both the domestic and international arena.

The criticality of materials to our national security cannot be understated. A thorough analysis of industries across the strategic materials value chain and the thoughtful development of government policy can successfully mitigate associated national security risks and provide a healthy economic environment for U.S. industry.

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