INDUSTRY STUDIES 2000

Strategic Materials

ABSTRACT

Strategic materials are those deemed to be of critical importance to national development and well-being. They include the following diverse materials: steel; aluminum; titanium; carbon-carbon and polymer matrices; and advanced ceramics, ceramic matrix composites, and metal matrix composites. Each of these materials differs from the others in terms of levels of technical and economic maturity and profitability. Overall, the materials industry has undergone a dramatic shift in the past decade, from a supplier value, supplier-centered industry to a customer -value, customer-centered industry. Instead of being viewed as commodities purchased by the pound, today's strategic materials are engineered products that significantly enhance performance and life cycle cost, and significantly contribute to the economy and to human resource development. Service, value, and processing are important, as are the consequences of the production processes.

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PLACES VISITED

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Army Research Laboratory, Aberdeen, MD

Bethlehem Steel, Sparrows Point, MD

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Instituto Scientifico Breda, Milan, Italy

Kvaerner Masa-Yards, Helsinki, Finland

Lentek, Milan, Italy

Museo Nationale delle Scienza e delle Technica, Milan, Italy

Noranda Technical Centre, Montreal, Quebec, Canada

Paldiski Submarine Base, Estonia [Former Soviet base]

Patria Vehicles Oy, Hameenlinna, Finland

Pratt & Whitney Canada, Montreal, Quebec, Canada

Rial Vacuum, Parma, Italy

SACMI, Imola, Italy

Silmet Metals, Sillamae, Estonia

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INTRODUCTION

In the broadest context, national security embraces economic capacity, social and political stability, and military power. The strategic materials industry is an important contributor to the national security strategy of the United States. Materials typically considered strategic in this context are steel, aluminum, titanium, other rare or exotic metals, and advanced polymer, ceramic, and metal matrix composite materials.

While some of these materials have been around for centuries and others represent state-of-the-art technology, all are key to maintaining the technological lead, competitive advantage, and military dominance that the United States currently enjoys. Economies thrive on constant improvement in the products and productivity-enhancing tools, machines, and processes that are the very heart of the materials industries. For example, in a military context, weapons system and aerospace applications require materials that are extremely lightweight, have high strength-to-weight ratios, high temperature tolerance, and are resistant to corrosion.

The push from the Department of Defense (DOD) to lower total ownership costs of weapons systems has resulted in efforts by material manufacturers to lower not only production costs, but also the operations and maintenance costs of the final products. With the increased emphasis on cost, the different strategic materials compete with each other for market share, as one material may often be substituted for another. There is also a growing requirement for materials to be recyclable in response to environmental concerns.

THE STRATEGIC MATERIALS INDUSTRY DEFINED

The diversity within the strategic materials industry compels restricting the scope of study of the contribution of structural materials to the national and world economies. Arguably, however, five classes of materials can be considered critical to U.S. military and U.S. national security applications: (1) steel; (2) aluminum; (3) titanium; (4) carbon-carbon and polymer matrix composites; and (5) advanced ceramics, ceramic matrix composites, and metal matrix composites.

Steel

The world’s primary metal material, steel is used in a variety of producer and consumer industries, including construction, shipbuilding, machinery, transportation, energy exploration, and appliances and other household goods. In 1993, the world used 735 million tons of steel against only 42 million tons of the next six metals combined: aluminum, copper, lead, nickel, tin, and zinc.[i] Steel usage still constitutes approximately 95 percent of all metal consumption in the world, and continues to be of dominant strategic importance to the world's economies.

Aluminum

Second to steel as the world's most widely used metal, aluminum is most commonly used in the transportation, construction, packaging, and consumer durable goods industries. Aluminum has captured its position primarily because of its excellent material properties (i.e., light weight, high strength, ease of recycling). Aluminum production reached 22 million metric tons in 1998 and is expected to continue to increase by about 3 percent annually. It is highly misleading, however, to directly compare aluminum and steel on the basis of gross tonnage, as aluminum's light weight and high strength-to-weight ratio distinguish it from steel. Because of these special properties, aluminum is increasingly being substituted for steel. Over the last few years, the transportation industry, particularly the automotive sector, has become the largest consumer of aluminum in the United States.

Titanium

Titanium competes in the marketplace as two separate and distinct commercial products, white pigment and titanium metal. While they start from the same raw titanium mineral feedstock, these two products are significantly different and in terms of production processes and market sectors are separate industries. Approximately 95 percent of worldwide titanium ore is consumed as white pigment.[ii] The remaining 5 percent is used to make titanium metal, a high-value-added strategic material used within the aerospace, marine, resource extraction, and medical industries.

The United States consumes annually approximately 20,000 tons of titanium metal,[iii] a figure that pales in comparison with the figures for steel and aluminum; the U.S. demand for steel is more than 6,000 times greater than the demand for titanium, while the aluminum demand is more than 350 times greater. Furthermore, titanium ingots are 10 to 15 times more costly than steel or aluminum ingots.

Nevertheless, because of its excellent mechanical properties (e.g., high heat tolerance, strength, and corrosion resistance), titanium has become the metal of choice in aircraft structure and aircraft engine design. It is also becoming increasingly the material of choice in medical prosthetics, a small but high-value-added application. The defense and commercial aerospace sectors account for approximately 50 percent of all milled titanium products.[iv]

Carbon-Carbon and Polymer Matrix Composites

Carbon-carbon composites are a Space Age technology in which carbon fibers are integrated in a carbon-fired matrix. Fabricated components are extremely lightweight, have high tensile strength, and withstand extremely high temperatures. Carbon-carbon composites are used in demanding friction applications, high thermal conductivity products, and advanced space propulsion systems. The nose cone of the Space Shuttle and new, more efficient rocket engines currently in development are examples of high payoff carbon-carbon applications. Carbon-carbon is also used for aircraft and automotive brake linings.

The polymer matrix composite industry provides materials for industrial components and consumer goods, as well as expensive, high-performance resin systems and high-strength, high-stiffness fiber reinforcement for aerospace, industrial, and automotive applications.[v] An advantage to using polymer matrices is the ability to custom-tailor the material by orienting the fibers to help direct the load. This cannot be done with metals. Also, because of their inherent durability, the life span of polymer matrix products is much longer than that of products made of metal.

Because of the high-performance requirements of advanced composites, comparisons between composites and more mature materials like steel and aluminum can be difficult and misleading. Advanced composites are expensive to produce. Thus, these materials are usually limited to very high value-added applications and are used only when other less expensive materials cannot meet the performance criteria required.

Advanced Ceramics, Ceramic Matrix Composites, and Metal Matrix Composites

Metals and ceramics (i.e., bricks, tile, and pottery) have been used for thousands of years. The 1950s, however, saw the beginning of an era of exploration for new materials to meet requirements that traditional metals or alloys could not. Advanced composites, combining high-strength, silicon carbide fibers with a matrix of metal or ceramic, provided the solution to many of these novel design problems. The aerospace industry initially generated these requirements with operational performance demands that outweighed materials development costs. This has led, over time, to a family of products that constitute the leading edge in materials technology. Applications and corresponding markets in electronics, transportation, medicine, environmental restoration, telecommunications, and consumer products are developing as the technology matures. These materials often require innovative manufacturing, machining, and fastener technology. Performance criteria include operation over a wide range of temperatures (greater than 2000°C) with little thermal expansion, high specific strength, and excellent resistance to corrosive environments. This technology has also required, and promoted, increased understanding of material characteristics from the molecular to the subatomic levels.

CURRENT CONDITION

The strategic materials produced globally and domestically can meet U.S. national security resource requirements. Although highly sensitive to economic cycles, the strategic materials industry overall is healthy. Like many other industries, it has become globalized; domestic firms are highly dependent on raw material imports and compete globally in commodity-like markets for both domestic and international market share. The critical materials stockpiles of the United States have been eliminated in recognition of this global market access to critical raw materials.

Steel

Globally, steel consumption reached a peak of 783 million tons in 1988, but this was followed by a steady decline to 693 million tons in 1998 due to economic downturns and the increased use of other materials.[vi] The consumption decline notwithstanding, steel prices from the 1980s through the 1990s kept pace with broad economic trends. Expected inflationary price increases were offset by the lower production costs that resulted from increased capital investment and productivity improvements. Steel prices correspond closely to the threefold increase in the consumer price index for services over the same period.

Domestically, the steel industry is a $70 billion per year business. United States consumption rose from 94 million tons in 1990 to 123 million tons in 1999. The United States requires approximately 124 million tons of steel per year, while its production capacity is 114 million tons, leaving a deficit of nearly 10 million tons.[vii] This makes steel imports inevitable.

However, domestic markets could not support both U.S. steel production and the dramatic rise in steel imports generated by the cyclical collapse in Asian markets. By 1998, Asia had moved from being a net importer of steel to a net exporter. Asian governments subsidized steel production capacity by nearly $100 billion between 1980 and 1992, and their excess production led to the recent steel-dumping activities that hurt the U.S. steel industry. Plant operations in the United States plummeted as significantly less expensive imported steel penetrated the U.S. market, and fourth-quarter 1999 earnings became a conspicuous casualty.

Traditionally, “integrated” steel plants have produced steel. There, the basic raw materials (coke, iron ore, limestone, and some scrap) are used first to produce iron, which is later refined into steel. Hot-rolling shapes the steel into billets, blooms, and slabs, and cold-rolling shapes these forms into the mill’s final products. The newer mini-mills use electric arc furnaces and rely primarily on steel scrap to produce slabs for shipment to cold-rolling facilities.

There are 15 integrated steel plants and 41 mini-mills throughout the United States.

In 1998, 54 million tons (55 percent of U.S. production) were produced in the integrated plants, and 44 million tons, in the mini-mills. The net return on capital is 2.5 percent for integrated plants and 4.5 percent for mini-mills, reflecting the fact that integrated mills require greater capital investment than do the mini-mills.[viii]

Aluminum

A handful of firms dominate the aluminum industry. The largest firms are Alcoa, headquartered in the United States, and Alcan, headquartered in Canada. A significant shift has occurred in the overall makeup of the industry since 1956, when the six largest aluminum firms controlled approximately 80 percent of worldwide production. Currently, that figure stands at 42 percent; a multitude of smaller firms that entered the market in recent decades serve the remainder. As of 1999, there were 12 domestic aluminum companies operating 23 smelters with a total capacity of 4.2 million tons; net domestic consumption was about 7 million tons.[ix]

In general, aluminum firms are integrated, in that individual companies control the entire production process from cradle to grave. They own and operate the bauxite mines, primary and secondary smelting facilities, semifabricating plants (i.e., casting, rolling, and extrusion facilities), finished product plants, and recycling centers. Aluminum is an extremely capital- and energy-intensive industry; the construction cost of a new smelter is on the order of $2 billion. Accordingly, the industry seeks a stable political and economic environment before investing.

Primary and secondary aluminum production facilities are located in different geographical regions because of their unique requirements relative to resources. Primary smelters are constructed where hydropower is abundant and electricity costs are relatively low; secondary smelters, which use a great many recyclable products, in industrial areas to take advantage of the availability of large quantities of scrap.

In today’s economy, investment capital is becoming more expensive for the aluminum industry, owing to the effects of increased capital flow to technology firms. This condition is driving industry consolidation. Alcoa, for example, recently acquired two smaller firms, Inespal and Alumax, through which it added more than 1 million metric tons of capacity, and is in the process of a merger with Reynolds. These and similar industry consolidations, however, are being closely monitored for compliance with antitrust law, both within the United States and internationally. The recent proposed merger of Alcan with the French company Pechiney failed scrutiny by the European Commission due to concerns over market concentration in beverage containers. Antitrust concerns in the United States have also generated significant government scrutiny of the proposed merger of Alcoa and Reynolds.

Regardless of the outcome of antitrust reviews, mergers represent the future of the global aluminum industry. The goal of these mergers is a consolidation of resources and markets in order to make North American and European firms even more competitive with Asian and Russian producers. These mergers may lead ultimately to a return of aluminum oligopolies and more international (i.e., global) orientation.

The aluminum industry's research and development (R&D) program is robust. Production of aluminum is one of the most energy-intensive industries in the world. In 1996, the industry spent about $2.5 billion on energy alone, approximately 25 percent of the cost of primary aluminum production.[x] Aluminum production constitutes approximately 2 percent of total U.S. industrial energy consumption. Consequently, a major focus of research is the development of advanced electrodes (used in the smelting process) and cell technology to improve energy efficiency and reduce polluting cell emissions.

Another critical R&D effort in the aluminum industry is the development of manufacturing technologies to support new applications of aluminum that capitalize on the metal's light weight and relative strength. One such application is in the automotive industry, where "light weight" translates to reduced energy consumption and lower environmental impact.

Recycling is critical to two corporate production goals: lower energy costs and reduced environmental impacts. Currently, 63 percent of aluminum beverage cans are recycled, and almost 90 percent of automotive aluminum is reclaimed and recycled. The motivation behind all this is energy conservation and consequent cost savings; aluminum production using recycled materials requires only 5 percent of the energy needed for primary aluminum production. Industry is, in fact, actively pursuing new initiatives to boost recycling rates.

Titanium

Although titanium is the ninth most abundant element in the earth's crust, and the fourth most abundant metal, finished titanium metal is very expensive due to high processing costs. World reserves of titanium concentrate are estimated at 370 million tons, or 75 years' worth at current consumption rates. Titanium prices are approximately $8 per pound; steel and aluminum, less than $1 per pound.[xi]

Titanium mineral concentrates are extracted mostly from heavy-mineral sands. These sands are the raw material for the production of processed titanium metal "sponge." Worldwide, production capacity to convert concentrate into raw material (i.e., "sponge") is currently limited to seven companies in five countries: the United States, Japan, Russia, Kazakhstan, and China.[xii] Currently, four domestic firms operate mining or concentrating facilities. Annually, U.S. mines produce approximately 340,000 metric tons of titanium concentrate, supplying both the titanium metal and white pigment industries.

The closure of RTI Titanium's sponge-making facility in 1992 reflects the choice by the U.S. titanium industry to redirect most of its investment capital from titanium sponge capacity to titanium melt and higher value-added fabrication capacity.[xiii] Timet and Oremet are now the only remaining U.S. firms that are integrated producers of both titanium sponge and "downstream" titanium mill products.[xiv],[xv] These two firms consume almost all the sponge that they produce. Since 1992, there has been a substantial shortage of domestic output versus domestic consumption of titanium sponge. Imports of approximately 10,000 metric tons per year have been critical to meeting the U.S. demand.[xvi]

Carbon - Carbon and Polymer Matrix Composites

According to the Composites Fabricators Association, the advanced composites industry has grown approximately 8 percent per year since its beginnings in the late 1950s. Today, the domestic industry output is over $27 billion per year. Carbon fiber output is growing significantly, with even the most conservative producers predicting 10–15 percent growth in output for each of the next 5 years. This predicted hike in production is expected to follow increased use of carbon in non-aerospace industries. However, current worldwide annual carbon fiber production has grown to about 50 million pounds, far exceeding the current demand of 25 million pounds.[xvii],[xviii]

Historically, advanced composites were required only in defense applications, and cost was not a major consideration. With the end of the Cold War, defense spending decreased, thereby reducing the demand for composite materials. The defense industry no longer constitutes the bulk of the market. As a result, many of the large chemical companies that entered the market in the 1980s departed in the 1990s.

Today, the U.S. advanced composites industry is predominantly one of small businesses,[xix] half of which are privately held. The product mix of these companies is diverse, with few firms producing only composites. The percentage of total company sales attributable to composites varies significantly, and firms still enter and leave the business frequently.[xx]

Academia, government laboratories, and composites-producing firms are actively involved in R&D efforts. A primary focus has been the behavior of materials in structural applications and the improvement of parts fabrication through the development and refinement of manufacturing processes. University- and laboratory-level research is aimed at a better understanding of the basic properties of the materials, particularly in the region of the interface between the matrix and the fibers. Additional R&D efforts have focused on new uses for advanced composite materials.

Even though R&D funding has declined since the late 1980s, 31 U.S. colleges and universities have undergraduate and graduate programs with a concentration in composites, and many sponsor composite research centers.[xxi] Partnerships exist between government agencies, universities, and industry for the purpose of establishing, sponsoring, and facilitating the development of centers of excellence in composite materials.

Advanced Ceramics, Ceramic Matrix Composites, and Metal Matrix Composites

The ceramic/composites industry currently has worldwide sales of $13 billion per year, with annual growth rates of 3–5 percent. Approximately half of the sales are in the electronics and information technology area, and about 40 percent of all sales are in the United States

The industry has free and open world trade, with no current calls for trade protection or restrictions. In 1981, the Japanese created, through their Ministry of Industry and Trade, a ceramic consortium that has contributed to their capture of 60 percent of the world market. In reaction, European and U.S. alliances have been formed over the past decade in an effort to develop organic industrial capacity.

Several pilot demonstration projects have been funded by various U.S. government agencies, including the DOD, the Department of Energy, the National Aeronautics and Space Administration, and the Department of Transportation. In the past 10 years, moreover, the development of several trade organizations has significantly improved industry and interagency alliances.

Conversely, Italy possesses small, technically competent firms that successfully penetrate niche markets on a global scale, and they do so without assistance from government. This is in stark contrast with the situation of Japanese and U.S. ceramics firms, which benefit from government R&D and export assistance. Domestically, factors that limit the increase in market share include a shortage of technical expertise and a lack of national test and evaluation standards for new materials.

Three national studies of the ceramic/composites industry during the past decade indicate a clear trend of U.S. growth and reentry into this marketplace. Typical of this trend is the outlook for Coorstech, the largest ceramics producer in the United States. This firm was recently spun off with the clear purpose of competing on the world stage. Annual sales grew 15 percent, and net income almost doubled from $8.7 million in 1998 to $16.8 million in 1999. More than 30 firms are engaged in production, and over 50, in R&D activities.

OUTLOOK

The strategic materials industry can meet national security resource requirements, but there are several areas of concern. Foremost among them are the lack of educated specialists, the difficulty in obtaining necessary capital, and reduced Department of Defense R&D budgets. In addition, each sector has its own trends.

Steel

The International Iron and Steel Institute predicts that global demand over the next 5 years will rise only 1.6 percent, with increased demands in North America and Asia offset by a 7 percent reduction in European demand. To survive this sluggish market, the global steel industry will continue the trend of privatization and consolidation. European transnational mergers, consolidations, and industry privatization have been ongoing since 1985. In Asia, the South Korean economy, in particular, is now recovering; but Japan has realized only marginal growth in gross domestic product in 1999 and 2000.[xxii] Asian recovery will increase world steel demand.

In the United States, the domestic industry's fragmented corporate structure has led to outdated facilities and a low level of capital investment. Charles River Associates, a recognized industry think tank, predicts major integrated mill consolidations over the next 15 years,[xxiii] a development that could benefit mini-mills by increasing the availability of pig iron.[xxiv] It is expected that by 2010, the mini-mills, because of improved productivity, reduced production timelines, the recycling of scrap materials, environmental improvements, and expanded product lines, will become the primary domestic steel producers.

The integrated mills can improve profitability by further consolidating marginal operations to reduce operating costs, fully utilize plant capacity, foster modernization, and reduce overhead. These companies incurred significant long-term employee benefit and pension liabilities as a consequence of the downsizing and modernization of the industry in the last 20 years. As these corporations slowly divest themselves of these legacy costs, the competitiveness of the U.S. steel industry should improve.

Future "dumping" of steel imports on the U.S. domestic markets, as occurred during the 1997 Asian economic crisis, will endanger the domestic industry. In such circumstances, domestic firms must cut production, resulting in inefficient plant operations, increased layoffs, and, in some cases, bankruptcy—all to offset the effects of lost market share. The U.S. steel industry has proposed that in the future, Congress impose duties more expeditiously to offset the effects of foreign steel dumping. Critics claim, however, that the consumer will bear the additional cost and that domestic customer industries will suffer in both domestic and international markets from higher material costs. How Congress will react is unknown, but whatever the reaction, it will greatly affect the steel sector.

Reliance on future World Trade Organization (WTO) and International Monetary Fund (IMF) mechanisms may be more fruitful than Congressional action. For example, as part of the $58 billion IMF bailout, the Korean government must divest itself of its 16 percent share of Posco, the world's largest steel company.[xxv] This significantly diminishes the role that the Korean government (and other foreign governments) might play in underwriting the operating costs of their firms.

Given its historical dominance of materials markets, steel faces unrelenting market pressures from all other materials; its future growth is threatened. The steel industry needs to actively promote higher value-added products, new products, and nontraditional markets if its materials' dominance is to be maintained. Greater use of stainless steel, the "ultra light steel auto body" (ULSAB), and residential construction are good examples of the kinds of initiatives the industry needs to pursue.

Aluminum

The outlook for the worldwide aluminum market is promising due to significant growth opportunities in the transportation and construction industries, mostly at the expense of steel. These market inroads will produce small, but steady, growth of approximately 3 percent annually. The key to aluminum's continued success will be emphasis on its fairly low life cycle costs. Technology advances resulting from extensive R&D activities will allow continued increases in productivity. This increase in productivity will have the dual effect of stabilizing prices while maintaining a reasonable return on investment. Additionally, mergers will continue to play an important role because of the advantages delivered by economies of scale in this capital-intensive industry.

Titanium

The demand for titanium metal is projected to increase steadily through 2002. Worldwide titanium use in such new applications as well-drilling equipment, sporting goods, and automotive structures is projected to increase from 5,000 metric tons in 1997 to 10,000 metric tons in 2004.[xxvi] One of the new-use markets expected to grow most rapidly is armor for lightweight combat vehicles.[xxvii] United States titanium companies are also enjoying limited success in the new-use marketing of titanium alloys. Aerospace applications include expanded use in undercarriages and an increasing array of cast parts. Titanium-based alloys are also being manufactured into automotive mufflers, valves, and lifters; storage containers for hazardous waste; and parts for petroleum-drilling rigs. Applications in geothermal or energy extraction equipment offer the greatest potential for increasing market share, as the energy industry continues to explore previously untapped areas of the world made accessible by stronger and more capable drilling rigs and equipment. Research and development efforts are likely to continue in these new-use areas. Until new-use applications generate requirements for large amounts of titanium, however, the success of the industry will remain linked to the aerospace applications.

The traditional aerospace business cycle[xxviii] is extremely volatile. Major titanium firms are developing long-term agreements with customers and suppliers in an effort to overcome the challenges posed by this volatility. This significant shift in strategy, coupled with the development of new-use marketing is intended to stabilize supply, pricing, and demand by increasing production volumes over the course of the traditional aerospace business cycle.[xxix]

Titanium may also be challenged in several markets, for improved manufacturing processes have made composite materials suitable substitutes in applications such as armor and aircraft engine components.

Carbon-Carbon and Polymer Matrix Composites

Industry experts predict that the use of composites will increase by 100 percent in the next decade, as the current excess capacity and increases in the number of applications will likely cause the price of these materials to fall.

Future applications will vary widely. Representatives of the composites industry believe that the requirements for weight reduction and lower maintenance costs are the major drivers for the use of composites. The corrosion-resistant properties of these materials make them extremely attractive to the medical community and energy extraction industries. The value of composites for drilling rigs and other oil exploration equipment could generate a demand for as much as 2 million pounds of these materials annually.[xxx]

Another potential application is in the repair or replacement of aging bridges. It is estimated that about 40 percent of the nation’s bridges are structurally deficient or functionally obsolete.[xxxi] Costs to repair or replace them have been estimated at close to $150 billion.[xxxii] Advanced composites are preferable to traditional repair materials in that these composites are less expensive, more durable, and amenable to the incorporation of innovative design features.

Carbon-carbon composites may also have a high-volume application in brakes, especially for commercial and military aircraft. Additionally, the United Kingdom is currently testing a light assault vehicle with a glass fiber hull, portending a new candidate material for the Army’s Future Combat System.

Research and development in advanced polymeric composites will remain focused on manufacturing processes, with advanced development efforts demonstrating additional applications, such as civil engineering and construction, marine systems, automotive structures, and some military applications. The impetus will come principally from smaller, more focused companies seeking to fill the rather low profit voids left by larger, more diversified chemical firms that are leaving the business.[xxxiii] These small businesses will position themselves close to R&D

centers of excellence, allowing them to leverage the intellectual capital that the centers generate and to employ the educated people that they produce.

Advanced Ceramics, Ceramic Matrix Composites, and Metal Matrix Composites

Ceramic/composite materials, although having been regarded as among the most promising of all new materials technologies for a number of years, have experienced the least market acceptance and penetration. Technology R&D partnerships between government, industry, and educational institutions have been developed to address the following key customer requirements:[xxxiv]

Industry	***Aerospace/Transportation***	***Military***
Equipment life	Equipment life	Range
Emissions	Pollution	Vulnerability
Maintenance	Cost	Cost
Energy efficiency	Fuel economy	Reliability
Recycling	Weight	Footprint

These partnerships focus on the needs of energy-intensive industries in an effort to offset rising energy prices or anticipated shortages in the coming century. The emphasis is on performance, cycle time, and cost competitiveness, and there is an established priority and sequence of research in each area.

Ceramics technology, in conjunction with biotechnology, was a cornerstone in President Clinton's recent announcement of a $3 billion increase in federal spending on science and technology. These positive actions are evidence of the recognition that future developments in these materials represent an engine for sustained growth and productivity. Indeed, the Information Age would not be possible without the likes of the electronic substrates, silicon wafers, and fiber optics that this industry has created over the past 20 years.

CHALLENGES

Increasing globalization poses three major challenges for the U.S. strategic materials industry: (1) maintaining and strengthening global partnerships to ensure continued access to critical resources; (2) maintaining a constant demand and stable prices for materials, thus to ensure stability and reduce market fluctuations; (3) shifting from a short-term to a long-term focus in developing new defense applications.   In addition, each industry sector faces its own specific challenges.

Steel

Three critical challenges confront the steel industry today: competition in existing markets from other materials, development of new markets, and the impact of foreign steel on U.S. markets.

The steel industry has only recently begun development of lighter, stronger, and more affordably priced steels to counter the gains made in the automobile industry by other materials such as aluminum, composites, and plastics. Historically, steel enjoyed a substantial advantage over other materials, as tooling and manufacturing processes were developed and installed with the intent of using steel. However, alternative materials have become more attractive as reduced weight and increased fuel economy have become more important. A good example of this response is the steel industry's development of the ULSAB, which reduces weight by 35 percent, improves fuel economy, and increases safety.[xxxv]

An underdeveloped market for steel usage is residential construction. The durability and strength of steel make it an extremely attractive replacement for wood. However, the steel industry must overcome the same challenges its competitors encountered when entering the automotive industry: the introduction of new manufacturing techniques and materials in an entrenched industry.

In the short term, foreign steel dumping will continue to have major adverse impacts cyclically on the U.S. steel industry. Foreign producers have historically continued to operate plants at high-output levels despite cyclical drops in global demand, and to dump the excess steel on U.S. markets. Dumping causes a significant drop in domestic steel prices, lost market share, layoffs, and bankruptcies in the domestic industry. The WTO may offer the best remedy to these circumstances.

Aluminum

The primary challenge confronting the aluminum industry today is maintaining and even increasing its market share. Aluminum's primary competitors are lightweight steel, plastic, and, increasingly, magnesium. Steel and plastic are lower cost alternatives, and they can easily replace aluminum if it becomes unaffordable. Magnesium is making a strong push into the automotive industry as a substitute for aluminum.

New, modern facilities and improved technology are required to increase productivity and reduce environmental impacts. Attracting investment capital will continue to be a challenge, especially given the low return on assets typical of this sector. Existing technical challenges could overwhelm the resources of all but the major aluminum firms. In an effort to solve technical challenges across the industry economically, firms are consolidating and partnering with government and academia in major R&D efforts.

Titanium

While the future of the titanium industry appears promising, it is also uncertain. Increasing competition from new materials, including composites,[xxxvi] and the fluctuating demands of the aerospace industry pose significant challenges to the titanium industry. In response, titanium firms are promoting growth in demand from other industries such as oil and gas drilling, and they are developing long-term agreements with customers and suppliers in order to reduce the negative effects of the volatile aerospace business cycle. The industry is also focusing almost all R&D efforts on manufacturing processes in order to make production more efficient and less expensive.

Carbon-Carbon and Polymer Matrix Composites

The greatest challenge to the carbon-carbon and polymer matrix composites industry is the high cost of material handling, capital equipment, and parts manufacture. While much of the constituent material production is automated, manual processes dominate the production of finished parts, including the cutting and shaping of reinforcing fiber materials, application of the matrix, and the handling of parts. The future of this industry is highly dependent on R&D efforts to reduce the cost of finished products. If these efforts are unsuccessful, the industry will lose ground to lightweight metals, such as aluminum, titanium, and magnesium alloys.

Another major challenge is convincing engineers and county inspectors to use composites where steel and concrete have traditionally been used (e.g., in the construction industry). The industry must educate engineers, project managers, and government officials on the advantages of using composite materials.

Advanced Ceramics, Ceramic Matrix Composites, and Metal Matrix Composites

The primary challenges in the ceramic and metal matrix composites industry are in three areas: (1) operational requirements, such as improved designs, increased reliability, decreased manufacturing costs, and increased manufacturing automation; (2) increased understanding of failure modes and microstructure properties, and consequent development of appropriate design standards; and (3) recruitment of more university graduates, particularly in coating and ceramic technologies. Owing to the shortfall in material scientists, the industry spends significant time and resources re-training chemical or materials engineering graduates in specific applications. Unless the United States can increase the number of educated professionals in these disciplines, the existing gap between the U.S. and Japanese industries will only widen.

GOVERNMENT GOALS AND ROLE

Given the diversity of the strategic materials industry and the intense competition between materials, a single government policy cannot best serve the entire industry. One policy may assist certain sectors of the industry while inadvertently harming others. Thus, the current policy of government intervention case-by-case is best for the industry.

The most critical role for the government is to ensure that all industry sectors continue to compete in free and open markets. Foreign government subsidies in the steel, aluminum, and titanium industries make it difficult for U.S. firms to compete in the global marketplace, particularly when products are "dumped" on U.S. markets at well below production costs. The government role should be to prevent mercantilist behavior on the part of foreign industries, the overall goal being open and fair competition in the global marketplace. Adoption and reinforcement of the WTO rules–based trade regime appears to offer the best solution.

The fragmented nature of the industry also makes it difficult to establish an overall research policy. Although the DOD's investment in materials R&D has been declining, the federal government continues to be involved through contributions to basic research at universities. The best thing the government can do is to maintain the existing level of oversight and insight, and to continue investing in R&D, especially in the development of advanced materials. Establishment and support of centers of excellence maintain the U.S. edge in high technology; sustain U.S. involvement in high-value, knowledge-based assets; and attract domestic and foreign investment and talent.[xxxvii] This infusion of brainpower and capital investment will help to preserve the competitive advantage of the United States and thus a worthwhile investment of taxpayer resources. Finally, some level of manufacturing technology investment would seem in order. Additional federal R&D funds would help fill the void left by reduced DOD demand, enhance performance, and reduce costs via process improvements.

CONCLUSION

The strategic materials industry is doing well as a whole, both globally and domestically. The global economy and future threats, however, could have a significant impact on the industry's future relative to U.S. national security. The government must continue to monitor this industry to ensure that strategic materials are readily available in both peacetime and wartime. Maintaining some capability to produce the broad range of economically and technologically strategic materials is clearly in our national interest. As an industry, strategic materials provide the means to sustain a strong economy (infrastructure, transportation, construction, and defense) and promote additional growth. Industry consolidation will improve efficiencies and maximize the return on capital investments.

A robust strategic materials industry will position the U.S. economy to better compete against the Asian and European Union economies. To be truly competitive in today's environment, where doing more with less is the norm, cost-effectiveness must become the overriding factor. Key to this transition is the establishment and support of R&D centers of excellence. The centers currently being established through the collaboration of various government agencies, industry, and academia should enhance the technological base of the United States and should attract intellectual and financial capital generally beneficial to the nation.

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