Evidence of a New, Value-Added Materials Paradigm

Louis J. Sousa

INTRODUCTION

Historically rich in natural resources such as iron ore, petroleum, and forests, the United States has long possessed a strong materials economy. Perhaps in no other decade was the strength of the U.S. natural resource-based materials economy greater than the 1950s when the United States alone typically accounted for close to half of the world’s production of steel, oil, and copper.

Accordingly, mining and metals were strong growth industries during that period. Between 1900 and 1950, per-capita national income for U.S. citizens increased about two and one-half times. During the same time period, U.S. production of copper tripled, iron ore increased by three and one-half times, and zinc quadrupled.

The 1950s belief that materials were considered national resources is best symbolized by the title that U.S. President Harry Truman’s blue-ribbon, high-profile Materials Policy Commission chose for its report: Resources for Freedom. The commission’s report contained numerous chapters on steel, aluminum, and other metals, as well as timber, agriculture, water, and energy. Prophetically, the report also contained a chapter titled “Technology: Resource for the Future.”

The strength of the resource industries in the 1950s was accommodated by a national consciousness that simply did not see environmental degradation. The nation instead was preoccupied with making up for the deprivation caused by almost a generation of economic depression and world war. Smokestacks were a symbol of national strength and economic vitality—not pollution.

MEGATRENDS AND MATERIALS

Foreshadowing other changes in the materials world, these lax attitudes about the environmental effects of unrestrained resource development would soon begin to be questioned. Indeed, by the mid-1960s, it was increasingly obvious that certain local ecosystems were excessively taxed. Thus, pressure began to build for a public policy response.

In 1970, the Clean Air Act was passed and the U.S. Environmental Protection Agency was created. Eventually, growing public concern about the impact of the production, use, and disposal of materials on the environment led to many costly regulations that began to affect materials producers in all phases of the materials cycle. Mining was restricted, metal smelters closed, products were banned, and operators were sued to clean up their waste dumps. Manufacturers began to design products with recycling in mind.

Then, not long after passage of the Environmental Protection Act, the materials economy experienced another jolt: a world oil embargo that precipitated steeply rising energy prices. The end of the era of cheap energy in the 1970s signified the end of an era for materials as well. Major tonnage commodity industries such as steel, aluminum, and cement relied on huge amounts of energy to convert ores and other raw materials into usable industrial materials. Dramatically rising energy costs in such industries pushed up materials prices.

This caused consuming industries such as automobiles to reduce the use of both energy and materials, especially metals. Abruptly, commodity metals industries in the United States matured into slow-growth industries.

As the 1970s progressed, a more integrated global economy emerged. Competitiveness became the overriding issue facing U.S. materials industries. In addition to tighter environmental restrictions, other factors—including a strong dollar, high capital and labor costs, poor productivity growth, alleged subsidies in other countries, and predatory marketing—limited competitiveness.

Moreover, manufacturers were under the same competitive pressures as their materials suppliers. The compelling need to cut costs and reduce waste forced manufacturers to further increase their efficiency of materials usage. This accelerated the maturation of commodity materials markets first noticed in the 1970s. In addition, global competition meant that manufactured goods increasingly had to compete not only on costs but on quality as well. As the total quality management concept spread throughout U.S. industry, manufacturers began demanding that their suppliers improve the reliability and performance of their materials. Consequently, U.S. materials producers found they had to work smarter and harder to sell less.

THE INFORMATION ECONOMY AND NEW STRATEGIES

While energy, environmental, and economic trends were rewriting the ground rules of the materials economy, another megatrend was gathering momentum: the increasingly information-intensive nature of the U.S. economy and the concurrent explosion in new technology. Eventually, materials producers found that the information economy further constrained the growth of commodity materials while proliferating technology led to a profusion of specialty and advanced materials.

Collectively, such trends have forced U.S. materials companies to rethink traditional business strategies. Much of the new strategy entails harnessing the potential of innovative technology. As markets for monolithic materials and commodity plastics mature, materials makers have begun to emphasize alloys, composites, laminates, and a variety of coatings that offer better growth prospects. Materials firms also are looking for ways to overcome the weaknesses of ceramics and more fully exploit their formidable strengths. Functional materials that do more than just support structures have been developed for use in sophisticated electronic, optical, magnetic, and biotechnology applications. Such new materials are more likely to be produced in small-scale, batch processes, unlike the large-volume, continuous-production processes that are typical of monolithic materials.

Another favorite strategy has been to invest heavily in downstream processing activities to add more value to materials and offset the contraction in commodities. Steel companies have invested in continuous casting; aluminum firms in can sheet and other fabrication operations; plastics and chemical companies in engineering plastics, specialty chemicals, and electronics; and glass companies in fiberglass, fiber optics, and advanced ceramics.

Adapting business strategies to changing technologies has altered traditional supplier-customer relationships in the materials business. Long used to merely taking orders, materials firms now work much more closely with their customers to help them solve specific materials-related manufacturing problems. Joint
ventures, licensing and other forms of cooperative agreement with customers, competitors, and universities have grown sharply. Strategic alliances have been formed with firms from previously alien industries such as medical diagnostics, textiles, and bioengineering, the skills and technologies of which have been found to be highly useful in certain areas of the materials economy.

As materials have become more information and technology dependent, a new value-added materials paradigm has emerged (Table I). Whereas commodity materials had symbolized the materials-as-resources paradigm, the new world of materials is increasingly characterized by both technology-intensive engineered materials and a proliferation of niche-oriented specialty materials. In turn, while price and availability have traditionally governed competition in materials, more highly specialized and technology-intensive materials and manufacturing processes have increased the significance of quality, performance, and service.

Another symptom of the emergence of a new materials paradigm is the changing nature of materials research. The surge in new materials brought about by advances in materials science and engineering has resulted in a race to develop commercial applications for these materials. Moreover, materials research increasingly focuses on synthesizing, processing, and fabrication to meet ever-more specific and stringent product specifications. Hence, the dominant thrust of materials research has shifted from the emphasis on resource recovery that prevailed during the 1950s to the more manufacturing-oriented emphasis of today.

Further, not only have the principal objectives of materials research changed, but so too have the methods. Whereas research performed by single principal investigators typified the simpler materials-as-resources paradigm, the evermore technologically complex world of the value-added materials paradigm increasingly requires a multidisciplinary, collaborative approach to research.

The federal government acknowledged the changing and more complicated nature of materials research by launching the Presidential Initiative in Advanced Materials a little over a year ago. The program is intended to improve the commercial payoff from the U.S. government’s $1.8 billion materials research effort by bringing about much greater interagency cooperation on materials research and encouraging closer collaboration between federal laboratories and the private sector. The materials initiative should help bridge the gap between the development (often in federal laboratories) of new knowledge about materials and the application of this knowledge (usually by private industry) in new and improved manufactured goods that can provide well-paying jobs and contribute positively to the country’s trade balance.

THE GROWING PROMINENCE OF THE CHEMICAL INDUSTRY

As the products, processes, competitive basis, and research focus of the materials sector have changed, so has the relative positioning of the principal players in the game. As the materials economy has gravitated from a predominantly centered on natural resources to a more technology-centered focus, the strength of the “chemical culture” has become more apparent. In comparison with the other major materials industries, the chemical industry far outsells its rivals on nongovernment research, and scientists and engineers constitute a greater portion of its work force. While domestic markets for many metals and nonmetals grew little during the last decade, U.S. production and exports of petrochemical-derived polymer and plastic materials surged at a six percent compounded rate of growth. Hence, by the early 1990s, chemicals had emerged to challenge the supremacy of metals in materials markets and issues.

Perhaps no trends better symbolize the changing roles of metals and chemicals in the U.S. materials picture than their respective international trade positions. While the U.S. metals trade deficit worsened during the 1980s, the chemical industry’s export surplus was second only to that of the aerospace industry of all U.S. manufacturing industries. What constitutes the largest component of the chemical industry’s enviable export position? Plastics and other polymer materials.

It is not widely recognized, but on a volumetric basis, the use of polymer materials in the United States exceeds that of all the metals combined, including steel. Moreover, there is a continuing trend toward stronger polymer materials that can compete with metals in a constantly growing number of uses. Innovative compounding and processing techniques have given plastics improved temperature and chemical resistance, strength, toughness, and similar properties once reserved for metals. As a result of such advances, plastics are being used in more and more applications.

But it is the growing use of particles, fibers, and other reinforcements in polymer composites that is opening the most exciting new frontiers for polymer materials. Advanced composites look especially promising for transportation uses because of their light weight and high-stiffness characteristics. The major target market, however—the ultimate battleground with metals—is automobiles.

The chemical industry’s technological leadership and marketing acumen in polymers and plastics have been applied to other materials as well—most notably electronics. Originally, all electronic components were manufactured by mechanical processes. Vacuum tubes, metal chassis, and copiers were requiring mechanical attachment, soldering, and hand wiring were the norm. Today, the molecular manufacture of electronic devices such as integrated circuits, optical fibers, interconnections, and data storage and recording media involves complex chemical processing steps.

The chemical industry has been able to successfully exploit electronic materials by turning high-purity requirements into high-tech processes, high-cost processes into high-value-added products, and undeveloped markets into high-growth ones. Electronic materials are symbolic of the changing materials economy and the elevated role of the chemical industry in the world of materials.

Moreover, solving the molecular engineering challenges posed by electronics gave the chemical companies improved understanding about the vulnerabilities of ceramics. In comparison with metals, ceramic materials typically can withstand greater heat, chemical, abrasive, and other stresses while simultaneously possessing less mass. The ability to take fuller advantage of the excellent structural properties of ceramics could extend the life or dramatically enhance the performance of a wide array of industrial