development related to other (civilian) needs in the economy. They contended that in addition to the bias exerted directly by selective expenditures of funds in certain areas, there was economic competition for available trained personnel, which tended to concentrate most of the effective scientific and engineering personnel in those fields receiving greatest federal support. They, among others, have pointed out the serious decline in our relative competitive position in an area in which this country used to be paramount—general industrial productivity.

Contrary to the conventional wisdom, it is now apparent that, in many important cases, the major reason for the encroachment of Japanese and European technology upon traditional American markets is not directly related to hourly labor costs. Instead, it is often due to increased sophistication and productivity in industrial production technology. Governmental policies and practices can have a large influence upon the disposition of available resources, including the technical labor force (*6*).

With regard to basic research and the university role, there are things that can be done to begin to utilize this set of national assets to alleviate some long-term materials resource constraints. It will be important, however, to focus on the optimum use of existing strengths, rather than to precipitously dismantle the apparatus that has been established for the successful pursuit of other goals. We should carefully think through the types of activities that can fit well into effective patterns of university, as well as industrial, action, rather than rushing off to make basic changes in our institutions.

Development of useful alternatives over the long run is much more than simple substitution among existing resources. In order to have more than a transient impact, we need to understand where, and more importantly, why, important materials are currently used. Knowledge of their functions (in fundamental terms of the structure and properties of the materials employed) in devices and of the various phenomena that control them will be important.

These questions are, of course, near the heart of the current paradigm in materials science; if this information were elucidated, sophisticated materials engineering might develop alternatives with the same property-related function as the commodity whose availability is under question.

It is imperative that we encourage increased attention to such matters by the nation's universities in such a way as to build upon existing strengths. Part of the problem will certainly be to interest and excite a community that has been oriented in a different direction and marching to a different drummer.

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Materials Supply: The Impact of Human Institutions

James Boyd

The industrial base of a modern technological society requires a vast array of raw materials, supplied in innumerable, constantly changing forms. This society provides its people with ample goods and services, only because it manages to secure adequate supplies of such materials as iron, steel, aluminum, copper, and phosphate. And contrary to recently proposed theories, the supply of these raw materials depends more on a succession of interrelated human institutions than on the resource base itself.

Throughout human history increasing numbers of substances have been discovered and more specialized needs have developed. These materials require reduction into useful states; they require mining or harvesting, concentrating, smelting, processing or refining, alloying or compositing, and fabricating before they become useful to society. Thus, sophisticated materials usage has mandated the formation of equally sophisticated human institutions; such an evolution formed the basis for the industrial revolution, which is still occurring.

Nature provides the basic resources; through a network of human endeavors and activities man discovers the needed minerals and converts them to the quality and form required by society. Man-made facilities produce the materials to meet the functional needs of society. Farms, harvested forests, mines, and oil wells do not spring "full blown from the brow of Jove." Rather, the basic resources that support the diverse materials-supplying activities must first be discovered through exploration. After discovery, they must be developed through such institutions as the capital market and corporations and through government policies. In the world of minerals, resources that can be converted, economically, into useful materials must be discovered and defined. Such resources, which form the foundation for economic progress, are termed reserves.

Reserves—circumscribed by location, quality, and economic viability—are finite. Further, they occur irregularly around the globe. Thus, no locality, state, or nation can be self-sufficient in all of the materials it needs or wants. Throughout history, this resource distribution problem has caused many wars. The development of transportation and trade has ameliorated but not eliminated this conflict in recent centuries.

Industry and consumers select and use materials on the basis of their ability to perform desired functions, and few desired functions cannot be performed by two, if not many more, different materials. The basic operation of society, therefore, does not depend on one or even several materials. As demands tax the ability of one commodity's resource base to supply all requirements, either new reserves evolve or more abundant materials emerge which can perform the required function. This process of supply involves continual dis-

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covery of new economic resources, advanced technological developments, and changing patterns of materials usage. It is a highly complex process indeed. Because of the dynamic nature of materials supply, the total resource base, when related to the foreseeable needs of mankind, looms extremely large. Therefore, while the cornucopia theory of limitless resources does not stand firm, the premise of material limitations impeding human advancement offers equally little validity. The principle of materials interchangeability, which expands the resource base, points to the use of human ingenuity and institutions to meet the needs of society.

Institutions of Discovery

The supplies of natural fibers being produced on the surface of the earth may be inventoried by modern aerial and earth satellite techniques. Eventually the rate of growth, the health, and the distribution of these renewable resources will be determined readily in this manner; the basic plans for their exploitation may then be made in an organized fashion to ensure the resource base for the world's total supply system. Because of this ease of discovery, the resource base of the natural fibers need not be discussed further in this article. The more difficult questions, which we must consider, revolve around minerals discovery.

The prospector, the original minerals explorer of the United States, is a familiar figure to all Americans. But the surface of the earth, in its accessible regions, has long since been examined very thoroughly; now the discoverers of minerals must search in more remote areas and at much greater depths. They must find nature's treasures in more secure hiding places. For discovery to proceed, government must make accessible, to the raw materials producers, lands that offer potential sources of future mineral reserves.

Modern science has developed many new tools to aid in the search for concentrations of minerals in the earth's crust. Thus, the explorers of today may start with data obtained from satellites, continue exploration by use of sophisticated instruments that can be flown closer to the surface of the earth, and proceed with geophysical and geochemical studies at the surface of the earth. All of these technological developments add to our ability to gain knowledge about the earth's crust; they supplement the geologist's limited visual capabilities. These tools aid in the art of exploration, which remains an art because the geologist necessarily operates in an inexact science.

Geologists then prove or disprove their theories by actual physical observations, by making tunnels, shafts, or drill holes. These hard slogging field techniques either yield a new reserve, demonstrate a temporarily uneconomic resource, or reveal the barren character of the prospect site. Of 10,000 conceptual deposits isolated by geologists in their initial examination of an area, only 1,000 will merit the application of such scientific exploration activities as detailed geophysical and geochemical examinations. Perhaps 100 will then be worthy of more extensive drilling—trenching, tunneling, or shaft sinking. Of those 100 sites, only 10 will warrant the major expenditure of funds to sink shafts, tunnel, or drill in detail. And of those 10 sites, evaluated so thoroughly, the odds are that only one will be immediately turned into a producing mine. Despite the development of many fine scientific tools, which yield invaluable data, exploration remains a very expensive and highly risky operation. The discovery of mineral deposits sufficiently concentrated by natural processes in the earth's crust is far from a sure proposition.

The cost of this risk becomes an institutional issue. Originally, when taxation was a minor factor, the ability to retain profits was sufficient incentive. As taxation became a dominant factor in project evaluation, most governments compensated for it either by making land available for exploration at little cost, by permitting the costs of exploration to be deducted as an operating expense against other corporate or individual income, or by rewarding risk-taking through certain tax mechanisms. Some governments permitted the eventual producing mineral operation to include in its cost, for the purpose of tax calculation, a percentage of its earnings; this tax mechanism is the depletion allowance, a form of depreciation applied to a wasting natural asset.

To attract sufficient money to support exploration activity, risk must be rewarded. The degree of reward, in large measure, must equal the degree of risk. If, for example, a successful mineral exploration project produced an economic entity that earned, for its investors, no more money than a savings account, that project would not get capital support. No one will undertake a risky enterprise unless he is assured that he will have possession of the asset when it is developed, and will be permitted to make more than the normal profit expected from a secure banking or manufacturing enterprise. But, in recent years, there has emerged a tendency to assume that the rewards for risk-taking in the discovery and development of mineral resources are unconscionable profits, and a burden on the rest of the population. Thus Congress and administrative agencies applied heavy royalty cost, withdrew federally owned tracts from prospecting under the mining laws, and eliminated the percentage depletion allowance for petroleum. Government, in making such moves, severely constrained the ability to discover new resources of minerals to meet the needs of society.

If industry is to provide society with raw materials from the earth at the lowest possible cost, it must be permitted to find deposits that can be produced most economically, given the current state of technology. Alternatively, exploration and development could be undertaken by government itself. I will not try to debate these alternatives here, but will leave it to the reader to visualize the reaction of a public servant in charge of the expenditure of public funds when he faces the enormous risks involved in the process of minerals discovery. Government employees traditionally orient themselves toward security rather than risk in the discharge of their public trust; to commit a risk-oriented program to such individuals might well ensure a scarcity of supply—and in short order.

Thus, the first activity in the chain of materials supply involves a diverse group of human institutions devoted to identifying natural resources that can be used to benefit the economy. Included are individual prospectors, corporate exploration departments, and corporations engaged, almost exclusively, in the exploration process. Geophysical companies apply specific remote sensing techniques; they assist geological organizations in finding geological conditions favorable for the concentration of materials. A variety of financial institutions support these activities. Certain government agencies provide access to some lands with potential resources; others provide financial incentives for undertaking these ventures. Additional government organizations use actual dollars to provide basic geological data. The delicate balance between these groups, and a favorable political climate, must be maintained if exploration teams and prospectors are to continue to maintain a reserve base.

Institutions of Supply

When a deposit has been identified as a reserve, it is next necessary to develop it into a productive property. This may involve preparing the surface of the land to permit the establishment of an open-pit mine; it may require sinking shafts or driving tunnels to expose and outline the ore body and to prepare an underground mine for production. Development includes construction of mills to separate the waste materials from the useful constituents of the ore and facilities to dispose of the waste. Concentrated minerals are seldom in the chemical state in which they are used. Smelters and refineries must be built to reduce the valuable minerals to useful metals or materials. Finally, the process of supply mandates the construction of additional plants to shape the raw materials to the exacting demands of modern technology—to draw wire, roll or extrude metals, and put them into the form in which they are eventually utilized.

The system of mines, mills, smelters, refineries, and fabricating plants requires vast expenditures of capital. These capital demands dwarf those normally associated with manufacturing; the gross capital investment and the capital investment per worker are on a scale not contemplated by manufacturers of plastics, textiles, or other products in the manufacturing sector. For example, the minimum investment to construct a new magnesium plant approaches \$75 million. Building an integrated complex to produce 125,000 tons of aluminum per year requires \$283 million. The construction of an integrated steel complex to produce 4 million tons per year costs some \$2.4 billion. That investment represents 3 percent of the present capability of the aluminum industry and 4 percent of steel capability. These data, supplied by the U.S. Bureau of Mines, demonstrate the enormous problem of marshaling capital resources to the materials supply industry (*1*).

The first institution related to the materials supply, then, is the financial market. The Chase Manhattan Bank estimates that some \$90.5 billion in capital will be required by the metallic minerals industry between 1974 and 1978 (*1*). The National Materials Advisory Board of the National Academy of Sciences estimates that the steel industry alone will have to invest \$3.5 billion per year for the next several years (*2*, p. 83). These prodigious amounts of money may be raised through the traditional financial (stock and bond) markets or borrowed from lending corporations.

Commercialization also involves the engineering consulting firms that provide the technological knowledge needed in the construction and operation of new facilities. These firms design new facilities to take advantage of the latest technical improvements. Virtually all minerals plants built today are based on new technical discoveries, inventions, or developments made since the last plant was built. Factoring these new technologies into facility planning requires a core of trained and competent scientists and engineers. It also requires a knowledge of the markets for minerals throughout the world. In all but such low-cost materials as sand, gravel, and limestone, prices are set by world markets, even though they may be controlled in part by individual governments or collections of governments. Therefore, a whole gamut of institutions in many nations must be involved in the basic raw materials industries if the requirements of an industrial world are to be met.

Supply Shortages and Institutions

Human emotions are fleeting, and memories very short. History remains unread, its lessons forgotten. For many years authorities had been predicting that exponential growth rates in consumption of materials and energy could not last forever. Shortages would occur unless corrective actions were taken. But it took long lines at gasoline stations, and seemingly endless delays in the delivery of goods, to bring the point home. In the same way, streams and atmospheres had to be visibly polluted before society perceived a need for changes in population growth, wasteful habits, and extravagant life-styles. Today much of this is forgotten; materials appear to be in copious supply to meet our depression-invoked diminishing needs. The urgency has gone out of the pressure to correct the fundamental forces which result in shortages.

In the meantime the environmental concerns brought the urge to change the course of society—immediately. Government demanded the expenditure of vast sums of money on equipment that would produce no product and generate no revenue. Neither the resource base nor the total environment demanded radical and sudden changes; further, the diverse organizations affected by those demands lacked the extreme flexibility needed to cope with abrupt departures from a tradition of meeting the economy's needs. These new demands shattered the delicate balance between institutions that participate in the processes of discovery and supply. Too much correction of one apparent evil resulted in far more damage to that balance than the physical deficiencies warranted. Savings, the only true source of capital, were forced into channels unresponsive to the marketplace.

Rapid application of environmental and safety regulations requiring costly investments in equipment and facilities that produce no product and are often beyond the financial capability of private industry. These problems are intensified by frequent changes in the regulations, which require further capital investments (*2*).

No matter how important environmental, safety, and health problems are, too rapid a diversion of capital results only in serious damage to the very operations that can correct the deficiencies.

In order to build facilities to protect the environment and improve health and safety the industrial base must expand, or our standard of living and our progress toward alleviating poverty will be degraded. Reduction of incentives to take economic risks and too rapid divergence of funds to worthy, but unproductive, goals have impeded the flow of capital to those institutions—the corporations—which supply the materials and erect the facilities to ensure both adequate materials supply and environmental protection. The delicate balance between the numerous institutions affecting materials supply must be reestablished.

Government Institutions

Among the institutions involved in bringing materials from the ground to use in society, government, the educational system, and the professional societies enjoy the most ubiquitous positions. They affect the process at all stages and in a broad variety of ways. Thus, these three organizations merit some specific comment and analysis.

Because the materials industries affect all aspects of society, and because almost all impacts on the environment result from the production, treatment, and use of materials, it is necessary that these industries operate within certain clear-cut rules. Their regulation emerges, largely, as a governmental function, for protecting both the environment and the total supply base is not a natural marketplace activity. Further, many costs associated with protecting the environment cannot be met by any one industry or group of industries; that conclusion was reached by the National Materials Advisory Board (*2*, p. 3). Thus, if the costs of providing a raw material base and protecting the environment are to be borne, they must be borne by society as a whole. And society's mechanism for accomplishing these tasks is its government.

The ultimate users of raw materials, the consuming public, seek satisfaction of their needs and wants. Therefore, an essential part of government policy is to ensure that the costs of protecting the environment become a part of the costs of production. Only then will the costs of environmental protection be borne by the ultimate users of natural resources. Unfortunately, Congress perceived a simplistic solution to this perplexing public policy question; it created a government agency with a single objective, resulting in activities affecting one phase of the total system without due regard to all others. Institutional imbalances resulted, disrupting the normal flow of materials to the consumers.

Government sets the ground rules within which private corporations undertake their responsibilities to society. It is essential, therefore, that the regulating agencies be operated in such a way that they provide stable rules under which the marketplace reflects the costs of common goals to the consumer; in many cases these inflationary impacts are unnecessary. Thus, the operation of government must be brought into balance with the operations of financial and corporate entities.

Educational Institutions

None of the institutions involved in materials supply can operate properly without employing individuals trained to understand the ramifications of technology, the financial structure of the marketplace, and the natural conditions under which these forces operate. This returns us to the fundamentals of our educational system. The acquisition and application of knowledge undergirds our entire society, our entire economy. And the institutions of higher learning serve both functions. Further, they serve as the basic knowledge transfer points.

Widespread and sound education remains fundamental to the understanding of our materials supply system. As the sum of our knowledge continues to increase, society must learn far more facts and understand many more principles and concepts. The development of sound thought processes in the young is critical to the health of the public and private structures involved in the production of raw materials. In that, the needs of the materials supply community do not differ from those of the other groups in society.

Today, because of the information explosion, young people find it increasingly difficult to achieve the level of knowledge necessary to accept responsibilities in human society with only secondary school backgrounds. Even those with college training may encounter serious problems. Professional responsibility frequently requires additional preparation. We have, therefore, built up engineering schools, advanced business schools, law schools, and graduate schools of science; these organizations train the minds of those who will eventually command much of our nation's productive activity. The educational institutions must nurture, protect, and advance the one most important resource—human intelligence.

Professional Societies

Scientific and professional societies evolved in the process of industrialization, both here and abroad. In these societies, individuals engaged in the same field exchange views and motivate each other to think more precisely about the solutions to broad or specific problems. They enjoy strong linkages with the universities—the custodians of the development of human knowledge. These professional associations stimulate the thinking that leads to developments based on the latest technological discoveries.

Some deride the American system for apparent overorganization; nevertheless, American professional societies continue to lead in the advancement of scientific and engineering knowledge. The technological community in this country and throughout the world benefits from the deliberations of American professional societies. Engineers and scientists engaged in education, industry, and government can assemble to discuss new developments in specific fields of endeavor. These discussions improve the operation of such specific disciplines, and of science as a whole.

The National Academy of Sciences, involving science, engineering, and medicine, is among the greatest professional societies created. Various agencies of the government can approach the Academy, which is as unbiased as human institutions can be, and gain its consideration of scientific subjects. Institutions such as the Academy are served entirely on a voluntary basis; they collect, in one place, many of the most knowledgeable minds available on any specific subject. They seek to come as close to the truth on any particular branch of knowledge as is humanly possible. If government institutions understand and accept their advice, our political system may work more efficiently.

Conclusion

Material supplies are the food on which an advanced technological economy and society lives. Natural resources, from which materials are derived, form the base of all material wealth. To further the goals and ambitions of any society, it is essential to provide access to that base at the lowest possible cost and to encourage its development. Each step in the supply chain, beyond the discovery of resources, is a multiple of that first cost for exploration and development of minerals. And the distribution of wealth is a function of the availability of materials to all those who need them. Bringing about this availability of minerals remains a problem of producing financing, government, and educational institutions.

The materials supply industries must operate smoothly if society is to function adequately; this efficiency of operation remains critical to the functioning of society because of the pervasive influence of minerals and fibers on human activity. Thus, the many institutions affecting materials supply must be operated in consonance and harmony. The imbalances caused by severe restraints imposed by one human structure on another, no matter how necessary, clog the gears of supply. The costs to repair institutional imbalances are inevitably borne by society's poorest members.

Because of the inextricable interweaving of human activities affecting materials supply, and the balance that must be maintained between these human organizations, knowledge and its application become premium considerations. Constraints, such as those necessary for protection of the environment and worker safety, must be applied by specialists who take advantage of the best knowledge available to them. These constraints must be developed to be responsive to all of the needs of society, rather than the specific desires of relatively small social groups. Further, since almost all human institutions affect the availability of materials, each organization must develop an awareness of the broader implications of its activities when it seeks to influence a specific segment of the materials supply system.

Abraham Lincoln stated in his Second Message to Congress: "The dogmas of the quiet past are inadequate to the stormy present. The occasion is piled high with difficulty, and we must rise with the occasion. As our case is new, so we must think anew and act anew. We must disenthrall ourselves, and then we shall save our country." Although the crisis he addressed differed from the present problems of materials supply, the attitudes he encouraged for this country remain germane. We must constantly think through our actions, and bring to bear the latest knowledge, if we are to assure a continuity of societal health and progress—economically and socially. We must constantly make our institutions responsive to our needs, and among those needs is materials supply.

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