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The New World of Materials

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After a short but severe recession, economic growth is beginning again in the United States and, more slowly, in other countries. But the economy will not be restored to the precise conditions existing in 1973. The reasons can be found in a new set of realities affecting energy and raw materials. That supplies of these basic commodities will remain adequate in the future can no longer be taken for granted. Indeed, the prospects for economic prosperity and perhaps for peace in coming decades will depend on how the world adjusts to new constraints and new expectations regarding these key ingredients of human endeavor.

What is new in regard to energy and materials is wide recognition that exponential growth cannot go on forever—a fact that has been brought home to many peoples of the world with especial force with respect to energy. It is not just a quadrupling of the price for oil in international trade but also the prospect of eventual physical limitations to its supply that is forcing this reconsideration. One by one the oil producers of the world will repeat the experience of the United States, where production reached a peak in 1970 and has since declined. Economies based on oil face the necessity of changing to other energy sources, a change that will have effects on the industrial and social character of the countries involved comparable in magnitude to the effects of the shift from wood to coal or from coal to oil and natural gas.

Profound changes are also occurring in conditions affecting the supply of raw materials. Among the new factors is a trend toward nationalization of foreign-owned mining properties or other measures to give effective control over natural resources to the host country. High energy prices are making prohibitively expensive the recovery of some low-grade ores and forcing reconsideration of energy-intensive processing methods, especially in the primary metals. New concern about the environmental impact of mining, lumbering, and materials processing and increasing restriction of access to resources on public lands are also constraining materials production in a major way. Taken together with financial markets that make raising capital difficult, these developments have created conditions dramatically different from those of a decade ago—a new world of materials. Indeed, what is perhaps most remarkable is that their cumulative impact has not yet disrupted the supply of materials in a major way.

Growing Nationalization

The lesson of the oil cartel's success in raising petroleum prices has not been lost on either the countries that export materials or those that import them. Thus far, efforts to extract higher prices for bauxite or other materials have not been too sucessful. But nationalization of copper, bauxite, tin, and, most recently, iron mines has been accelerating, with more than 12 Third World countries taking such actions during 1974 and 1975. Last year, for example, Venezuela nationalized several mining properties that supplied 15 million tons of iron ore annually, an amount equal to 30 percent of the iron ore imported by the United States. The expropriation of mines by these developing countries and the declared intent to ultimately control their own natural resources by many more have drastically altered the international materials climate and introduced a new and largely negative element into the calculus of investment in resource development. Attention to where supplies of raw materials come from and their vulnerability to sudden interruptions has become very keen among industrial executives and has stimulated new consideration of alternative sources of supply.

For the United States as a whole, imports constitute more than half of the supply of aluminum ore, tin, chromium, asbestos, and nearly two dozen other important materials. For a few key metals, the effects of a sudden cutoff could be very disruptive indeed. Stainless steels, for example, depend on chrome. Obviously, prudence dictates that stockpiles of the most vulnerable materials be maintained. Given sufficient time, however, new sources of supply can be developed or alternative materials that serve the same function can be brought into use. The demonstrated existence of the necessary technologies can, in fact, serve as a deterrent to cutoffs or a restraint against drastic price increases. There is yet time to develop the requisite technologies for a number of vulnerable materials before such situations arise, rather than playing catch-up as in the case of energy technologies alternative to oil.

Energy use is a pervasive consideration throughout the materials cycle, from mining or harvesting, to processing, to disposal or recycling. Nearly 16 percent of U.S. energy consumption is now devoted to materials production. Wood product industries are somewhat of an exception among materials producers in that they can supply a substantial portion of their energy needs by burning wood chips and other waste, and are thus buffered to some extent from the effects of higher energy prices. Other materials producers are not so fortunate.

For most minerals, the largest portion of energy use occurs in concentrating the raw ore prior to smelting or other processing. Low-grade ores require the crushing and grinding of much higher volumes of material and are thus more consumptive of energy. Given enough low-cost energy, of course, there is no limit to the grade of ore that can be exploited. But in practice, high energy prices are an increasingly severe constraint that has focused new attention on less energy-intensive means of extracting and processing ores and has raised new questions about ultimate limitations to materials supplies. It now seems unlikely, for example, that copper ores containing less than about 0.1 percent copper will be mined at all (the ores currently mined average about 0.7 percent copper). The trend to lower-grade ores as richer deposits are exhausted will intensify the energy squeeze on the materials pipeline.

Declining grades of ore also place materials needs on a collision course with environmental aspirations, since they imply larger volumes of mine spoil. A more fundamental constraint is increasing awareness of the health hazards associated with leakages from the materials cycle of such substances as asbestos, halogenated organic compounds, and heavy metals. The costs of cleaning up water effluents from mines and materials processing plants to meet the standards mandated by existing laws is estimated at about $20 billion over the next 8 years, which gives a measure of the effort required. Higher prices for materials and continuing, perhaps growing tension between environmental values and the availability of materials appear likely.

With such constraints, the long-term prospect for expanded supplies of raw materials is mixed at best. Barriers to development and exploitation of materials resources are to some extent balanced by improving techniques for finding and winning minerals from the earth's crust. Knowledge of how ores are formed is being advanced by the concept of plate tectonics, and the Earth Resources Technology Satellite is proving most useful in discovering ore deposits. Application of modern biological science and management techniques seems to promise improved yields and more abundant supplies of renewable materials such as wood. It is even possible that the demand for materials, at least in the United States, could grow much more slowly in the future. A recent Harris poll showed that 90 percent of those polled—a figure so high as to constitute a mandate—agreed that "we here in this country will have to find ways to cut back on the amount of things we consume and waste." Nonetheless, even maintaining the present materials base will be increasingly difficult in coming decades.

Among the most rapidly growing constituents of the materials base are wood products, plastics, and other synthetics. The economy is especially dependent on products derived from natural gas and petroleum. The annual tonnage of such synthetics is somewhat less than that of steel, but in volume they surpass it. Most of the basic feedstocks for these materials could be derived from coal, wood, or plants. Indeed, at one time the nation's supplies of ethyl alcohol, acetone, and butanol were produced by fermentation of grain or molasses. These three chemicals are or could be used as a substantial fraction of the inputs for plastics and other synthetics. A convenient starting material might be glucose obtained from the starch of grains or the cellulose of trees by hydrolysis. These examples serve to illustrate the point that there appear to be many new opportunities to exploit the feedstock potential of renewable resources and of coal, opportunities created by the high price and, ultimately, the scarcity of hydrocarbons from oil and natural gas.

Similar considerations point to another long-range opportunity or even necessity, that of finding a broader range of uses for the abundant minerals of the earth's crust. These minerals and the materials such as glass and cement that can be made from them are derivable from common rocks, a source of supply that is not vulnerable to foreign control. Research into what can be done with such materials would benefit the rest of the world as well.

The materials research effort in this country has shown an impressive ability to explore basic physical and chemical properties and to create new materials or old materials with new properties with that knowledge. These discoveries have often set the pace for the development of new and more sophisticated technologies. Of equal importance, however, are questions of raw materials supply and of industrial processing under energy and environmental constraints. These areas have received less emphasis, especially in academic institutions, but are central to the functioning of the economy. They deserve more attention in the future.

Looking to the Future

This special issue was inspired by the new conditions surrounding materials supply and seeks to examine in more detail many of the themes and problems mentioned above. More extensive treatments of materials supply can be found elsewhere (a selected list appears in the bibliography). For the most part, the articles of this issue are future-oriented. Usually when attempts are made to look ahead, the seers tend to predict disaster or utopia. The consensus of the authors in this volume is that there are problems but, at least in principle, they are solvable. A representative sample of the tone of the content is provided by Landsberg in his overview of recent trends and issues. He points out that the United States has not been experiencing exponential growth in the use of materials. During the past two decades consumption has been about level. Landsberg minimizes the disaster scenario presented in the Club of Rome's 1972 report. He is skeptical of the view that he imputes to the Club of Rome "that materials exhaustion looms as one of the horsemen of their special breed of Apocalypse and could bring civilization tumbling down." He cites contrary arguments and viewpoints.

Nevertheless, Landsberg is not complacent. He points to a new societal hostility to the discovery and production of materials. The arena of action ranges from removal of land from exploration to stringent regulations affecting extraction or harvesting, treatment, and transformation. An important development is withdrawal of federally owned land from mining activities. Prior to 1968, only 17 percent of these lands were forbidden to mining. By 1975 the total had risen to 67 percent, with the prospect that all might be forbidden by 1980. These lands comprise about one-third the area of the United States and contain much of the best potential mineral resources.

In his article on international trade, Fried discusses the great commodity price boom of 1971–74. During that period prices rose by 159 percent. In 1972–73 they jumped 67 percent. These increases were the largest in the past 115 years.

The boom in commodity prices began before the sharp rise in oil prices. It was in part conditioned by imbalances in supply and demand, which led to fears of an era of permanent shortages. Once the inflation began it fostered instability of currencies and speculative fever. As an example, Fried points to the role of the Japanese in amplifying price fluctuations and cites figures for their imports and exports. For example, their annual imports of copper have been averaging about 270,000 tons and exports about 30,000 tons. In 1973 imports rose sharply to 395,000 tons. This was followed in 1974 by exports of 280,000 tons. In 1973 the price of copper hit a high of about $1.50 a pound. In 1974 the price dropped to as low as $0.52.

In his analysis Fried emphasizes the cyclical nature of the commodity boom. He urges that the present period of relief from hysteria be used to take measures to avoid future shocks of boom or bust. One step would be to create buffer stocks that could be increased during periods of low price and made available when prices rose.

The cost of various forms of energy will be a crucial determinant of the kinds of materials that are available and are used in the future. If energy were to be abundant and sufficiently cheap, very low-grade deposits could be utilized. However, in the future some forms of energy, notably hydrocarbons, will not be cheap and abundant. Dependence on foreign sources of oil will grow rapidly during the next 5 years, rendering the whole economy, including materials aspects, vulnerable to sharply advancing costs and even stoppages of supplies.

Fig. 1. Copper ores as low as 0.4 percent copper are recovered from Kennecot's Bingham mine near Salt Lake City, Utah. However the low grades are economical in part because some precious metals are also recovered. (Photo courtesy of James Boyd, Materials Associates, Washington, D.C.)

Accordingly, an examination of the usage of energy in the winning and processing of materials is relevant. In addition to being aware of costs and availability of materials, we need to know their energy costs. In this issue Hayes provides substantial information concerning the energy consumption involved in the production of materials of major importance.

Two articles, one by Cook and the second by Goeller and Weinberg, explore the limits of exploitation of nonrenewable minerals resources; energy is an important consideration in their comments. The first article provides some historical background as a basis for extrapolating into the intermediate future. The second article looks at the more distant future.

For many years economic geologists have warned of coming exhaustion of important minerals, and indeed the rich deposits of many ores have been exhausted. However, development of new methods and efficient earth-moving equipment and abundance of low-cost energy has permitted exploitation of lower-grade ores. At one time the cutoff grade for copper ore was 3 percent. Now in some places a content of 0.35 percent is exploitable (Fig. 1).

However, Cook cites information on copper ore bodies which leads him to believe that in the long term it will become extremely difficult if not impracticable to obtain large supplies of copper. He points out that the volume of recoverable copper does not increase very greatly as the ore grade drops lower than present levels. He also mentions the exhaustion of mercury ore deposits in the United States. It seems plausible that supplies of some elements will one day be effectively exhausted.

Goeller and Weinberg are very optimistic about future supplies of materials, provided adequate energy is available. They recognize that reserves of some individual elements may become largely exhausted. However, they point to the relative ease of substitution. For example, copper as an electrical conductor can be replaced by aluminum. They cite a study of the use of mercury which demonstrates that virtually all of the functions served by that element can be filled in other ways. Moreover, the major tonnages of inorganic materials that are presently used are derived from abundant elements, particularly iron and aluminum. Looking a distance into the future, they foresee only a limited number of possible problems of scarcity—phosphorus, and energy in the form of CH_x. From this discussion and from other items in this issue, one draws the impression that given time and supplies of energy, technology and science can provide the necessary flexibility to gradually overcome scarcities of particular materials. At the same time, it should be obvious that often as long as a decade or more must elapse before the system can adjust fully.

If our industry were to be suddenly denied supplies of an element vital to high technology, dislocations could occur that would last for some time. Even mild shortages could lead to sharply higher prices for specific items. At present there are some 23 minerals for which the United States must import most of its needs. A Bureau of Mines program described by Kirby is aimed at reducing potential vulnerability by testing methods of winning supplies from indigenous materials. It also serves as a form of technological insurance against excessive price demands from foreign suppliers. An example is work designed to produce alumina from domestic sources such as clay or anorthosite. At present almost all supplies of alumina are imported. The program will examine a number of different methods in pilot plants. Should a crash program later become necessary to provide domestic sources of alumina, years would be saved in arriving at full-scale production.

Chemicals produced annually from oil and gas have a value in excess of $30 billion. The products are important to many aspects of the economy, including agriculture, clothing, home furnishings, and transportation. Feedstocks to produce the large variety of products take about 10 percent of the oil and gas supply.

At one time many of the feedstock chemicals were obtained from coal, primarily as a by-product of coke ovens. However, from about 1950 on, the principal source was petroleum. Oil and natural gas had advantages of price; they also were clean. Moreover, the oil industry processes huge volumes of fluid and is adept at plucking out individual chemical species. So large is the volume of processed oil that even a minor constituent is available in substantial tonnages.

However, petroleum reserves of the United States are declining. We face a future in which availability of petroleum feedstocks is uncertain and in which they may be very costly. Because of the long time span required to convert small-scale studies to large production plants, it is appropriate to examine alternative sources of organic chemical feedstocks. Coal is one of the major potential sources. In this issue, Squires surveys the current state of the art of obtaining chemicals from coal and identifies new and promising findings that represent substantial advances over the older coal tar techniques. Among other topics he discusses gasification with steam and oxygen, partial gasification with steam, flash pyrolysis, and flash hydrogenation. The latter two processes seem particularly promising.

Chynoweth provides insights on the interaction of materials and high technology. High technology is a major user of many of the rarer elements, but at the same time advances in technology have led to great savings in the use of energy and materials in performing a given function. Chynoweth cites the simple example of the modern solid-state calculator, which has replaced the earlier heavy mechanical version. Small silicon chips with their complex circuitry fill the functions of great numbers of vacuum tubes, resistors, and condensers. They do this reliably and with little energy cost. Chynoweth points out that the replacement of mechanical calculators by solid-state devices is a higher order of substitution than, for example, aluminum for copper, and he refers to it as a functional substitution. Other examples cited are the use of adhesives instead of nuts and bolts for joining and of jet engines instead of piston engines and propellers in aircraft.

Chynoweth cites further examples of contributions of solid-state electronics to conservation of materials through miniaturization and through substitution of functions. The power of the ingenuity of the electronics industry is such that it is capable of vast changes and adjustments and of responding to evolving constraints in the costs of energy and materials. The picture implied in Chynoweth's vision is a society whose standard of living increases while use of energy and materials declines.

The Potential of Wood

At one time wood was the principal energy source for the United States. But after 1860 it was gradually supplanted by coal, and it came to be used mainly for building materials and paper products. As long as vast areas of virgin timber were available, there was little effort to improve silviculture.

With large amounts of cheap oil and natural gas available as feedstocks, there was little incentive to explore the chemical or energy potential of trees. Recently, with the general realization that petroleum resources are finite, diminishing, and likely to become more costly, increasing attention has been focused on wood. The potential of trees as renewable resources of materials, chemicals, and energy is substantial. About a third of the land area of the world and of the United States is forested. The biological potential of wooded areas is such that with a vigorous effort the United States could, in principle, maintain an austere but satisfactory economy based on trees as a principle energy source. Recent experiments have shown that wood can be converted by hydrogenation into liquid fuels. Wood has the advantage of being relatively ash- and sulfur-free. The growing stock of the world's forests totals about 300,000 million cubic meters of wood with an annual increment of about 3,000 million cubic meters, which might be substantially increased by better management.

Thus wood has large potential as a long-term renewable resource applicable to needs for energy and materials. Recognizing the important role of wood for the future, a National Academy of Sciences committee headed by J. S. Bethel has been conducting a study on renewable resources for industrial materials. Three articles related to that study appear in this issue. Emphasis is on the use of wood principally as a source of building materials and of paper and related products. The total quantities involved are impressive. Jahn and Preston point out that annually 250 million tons of raw wood is processed—an amount about equal to the production of all metals, cements, and plastics. An important use is in structural materials, and here wood has an important energy advantage. For example, steel floor joists require 50 times as much energy as their wood counterparts. Aluminum framing for exterior walls is about 20 times as energy-intensive as wood framing.

Spurr and Vaux provide an analysis of the biological potential of U.S. forests. They state that potential growth is much greater than current growth. Much of the western forest land is still covered with old-growth forests, for which net growth is negligible because the rate of mortality approximates the rate of growth in the surviving trees. They cite a number of ways in which yields could be improved, including introduction through planting of genetically faster-growing trees.

In the three articles related to the Academy study there are repeated references to institutional impediments to effective management of our wooded lands. One factor cited is the federal government. This unwieldy giant comes in for special treatment in an article by Clawson. He takes an economist's approach to federal management of its forests. He estimates that the timber on the public lands has a value of $42 billion and points out that the government obtains only about a 1 percent annual return on this huge sum. In comparison to private enterprise, this performance is very poor. Moreover, in the forests managed by industry, net growth per acre is almost double that on federal lands.

Renewable resources are crucial to an enduring human civilization. The articles herein dealing with this topic leave the impression that this nation has not yet got its priorities straight. Indeed, materials of all kinds are so basic to the continuance of our society that the country would be well served by increased attention and—more to the point—some constructive action to insure a continued supply.

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