The interweaving of energy losses in metallic and energy mineral processing can be dealt with, but only through a total systems analysis. Chapman (*5*) cited data on smelting copper by thermal-fired compared to electrical-heating sources. At first glance, electricity is favored 2 to 1 on the basis of heat input, but when heat rate is factored in the ratio is almost 2 to 1 against electricity. The moral of this example is best expressed in Chapman's words: "It is a disturbing conclusion that in good faith an industry could improve its own thermal efficiency whilst increasing the national energy consumption."

It is that total systems analysis, of true energy costs and possible real energy savings, which is required if industry is to meet society's demand for materials in a world where energy, in all forms, is becoming increasingly expensive.

References and Notes

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Tensions Between Materials and Environmental Quality

Environmental regulations will constrain the availability and increase the cost of materials.

Richard A. Carpenter

Concerns about environmental quality interact in a complex way, depending on supply and demand of materials, to change usage patterns, availability, and costs. The energy and materials conversion systems of industrial society are closely linked to natural systems of photosynthesis and biogeochemical cycles. The National Commission on Materials Policy (*1*, p. 6-1) concluded that:

> The material resources and environmental quality of the Nation are affected by a lack of consideration of the two as a unit. Depletion of reserves and pollution have the same cause—failure to manage the flow of materials as a cycle, resulting in a resource depleting dispersal of energy and materials into the environment as pollutants. A national policy for the management of energy and materials is needed to transform this open-ended process of wastage into a substantially closed system.

This relation is well recognized but very difficult to deal with. Thus, considerations of major parts of the whole, such as this special issue on materials, are practical devices for analysis and planning only as long as the total context is not forgotten.

Environmental quality is a relatively recent gathering point for a variety of measures—both quantifiable and subjective—of importance to the management of natural resources. The National Environmental Policy Act of 1969 sought to place the full fair weight of environmental values on the scales of the decision-making process. The Congress declared a national policy "to create and maintain conditions under which man and nature can exist in productive harmony ..." (*2*). The National Materials Policy Act of 1970 sought to "enhance environmental quality" and develop a policy "to anticipate the future materials requirements of the Nation and the world ..." (*3*).

The mixture of objectives within and between these two recent legislative expressions of national policy shows the development of thought about natural resources management. Neither exploitation nor preservation is dominant as a concept; a continually refined balancing among many goals is what is called for. Rather than making simple decisions whether or not to proceed with individual projects, the manager of natural resources is challenged to generate imaginative alternatives taken from as comprehensive a view as is reasonable. Trade-offs are to be made explicitly and in a process open to the public. The marketplace, with its time limitations and imperfect information about environmental impacts, has been augmented (or perhaps supplanted) by a growing array of assessment procedures and regulations. In fact, the single greatest source of tension between availability of materials and environmental quality may well be the increased difficulty and time lag involved in reaching acceptable decisions.

The desirability of balancing competing and often conflicting objectives in the use of natural resources leads directly to a second major problem: the dearth of complete, accurate, and timely information. Cause and effect relationships in ecosystems are not well understood because of the complexity of organisms and their environments. Ecology is not a predictive sci-

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ence in the sense of chemistry or physics. As for materials, far too little is known about their reserves, substitutability, and need as opposed to the demand for them.

The economic and social consequences of manipulating the cost and availability of materials to achieve some environmental quality or conservation goal are uncertain. Opinion polls record sustained support for control of environmental pollutions and a recent report by the Harris organization says 77 percent of Americans polled "would prefer a more modest life style over continued inflation, shortages, and repeated recessions" (*4*). However, this may not represent the view of the poor and disadvantaged who still aspire to greater material well being.

As a consequence of the lack of information, the codification of public concerns about environment and materials has resulted in elaborate administrative procedures for examination and use of a generally sparse data base. The following list comprises some of the current laws applicable to environment and materials questions:

National Environmental Policy Act of 1969 [42 U.S. Code 4321 (1969)]
Federal Water Pollution Control Act Amendments of 1972 [33 U.S. Code 1251 (1972)]
Marine Protection, Research, and Sanctuaries Act of 1972 [33 U.S. Code 1401 (1972)]
Clean Air Act Amendments of 1970 [42 U.S. Code 1857 (1970)]
Solid Waste Disposal Act of 1965 [42 U.S. Code 3251 (1965)]
Mineral Lands Leasing Act of 1920 [30 U.S. Code 185 (1920)]
Mining and Minerals Policy Act of 1970 [30 U.S. Code 21a (1970)]
Occupational Safety and Health Act of 1970 [29 U.S. Code 651 (1970)]
Coal Mine Health and Safety Act of 1959 [30 U.S. Code 801 (1959)]
Multiple-Use Sustained-Yield Act of 1960 [16 U.S. Code 528 (1960)]
Wilderness Act of 1964 [16 U.S. Code 1131 (1964)]
National Park Service Act of 1916 [16 U.S. Code 1 (1916)]
Federal Food, Drug, and Cosmetic Act of 1938 [21 U.S. Code 301 (1938)]
Federal Environmental Pesticide Control Act of 1972 [7 U.S. Code 135 (1972)]
Federal Highway Act of 1966 [23 U.S. Code 138 (1966)]
Federal Power Act of 1920 [16 U.S. Code 800 (1920)]
Land and Water Conservation Fund Act of 1944 [16 U.S. Code 460 (1944)]
Oil Pollution Act of 1961 [33 U.S. Code 1001 (1961)]
Endangered Species Conservation Act of 1969 [16 U.S. Code 668 (1969)]
Taylor Grazing Act of 1934 [43 U.S. Code 315 (1934)]
Fish and Wildlife Coordination Act of 1958 [16 U.S. Code 661 (1958)]
Wild and Scenic Rivers Act of 1968 [16 U.S. Code 1271 (1968)]
Outer Continental Shelf Lands Act of 1953 [43 U.S. Code 1331 (1953)]

My discussion is drawn largely from recent advisory reports by the National Research Council, which assesses the technical basis for making trade-offs in the energy, materials, and environmental system. These reports agree that tensions between materials availability and environmental quality will increase in the immediate future (*5*, p. 2).

> Given the present level of technology and what may reasonably be expected to evolve over the next decades, and given the prevailing view that materials consumption is the way to a better life, the facts indicate (1) materials throughput will double, and then double again, over the next thirty or forty years, (2) the quality of ores and other natural resources will decline and readily available sources be exhausted, (3) only by increased use of energy per unit of output and per capita will the intensity of materials throughput be maintained, and (4) the environmental stress per unit of production will increase correspondingly.

Pollution Control Regulations

Federal, state, and local regulations on the discharge of pollutants into the air or water have reached a stage of enforcement such that profound changes are taking place in manufacturing and processing industries. The gross and obvious pollution problems (for example, particulate matter in air and oxygen-demanding organic wastes in water) are being alleviated without much argument. Current regulations prohibit many materials processing practices of the past, such as those that led to sulfur dioxide damage from smelters in Tennessee and Ontario, hydrogen fluoride from phosphate plants and aluminum smelters, and heavy biological oxygen demand loadings from pulp and paper industries.

These clean-up efforts require relatively large amounts of capital that in some instances is being diverted from the plant construction and improvement that would otherwise be devoted to supplying additional materials. Power plants, cement plants, paper mills, ore processing operations, steel mills, and petrochemical installations are among those affected by large capital costs for pollution abatement, outlays which usually yield no return on investment although they are justified in the national interest. The availability of otherwise usable materials is thus constrained (*1*, p. 6-14).

Another demand on capital is for research, development, and innovation in the basic materials industries. A recent report of the National Materials Advisory Board gives the results of a survey of forest products, glass, steel, and plastics industries. In each the ability to attract capital for technological improvements has been adversely affected by government regulations on price, profit, safety, and environmental correction (*6*).

The staff draft report of the National Commission on Water Quality (*7*) estimates the capital costs for achieving the pollution control mandated by the Federal Water Pollution Control Act Amendments of 1972. Table 1 is adapted from that report to show data of interest to the materials industries.

As emission restrictions for new plants become progressively more stringent, changes in processes and products become less costly than discharge treatment in achieving environmental protection. These design revisions are altering raw material requirements and by-products.

The use of materials for pollution abatement may affect their supply for other uses. For example, by-product lime from the calcium carbide process is insufficient to meet the demand for sulfur oxide scrubbers in electric power plants and smelters. The use of noble metal catalysts in controlling automobile exhaust may have the eventual effect of concentrating platinum and palladium (in the used converters) for recovery and reuse.

Pollution control through the elimination of wastes can also be a new source of materials. It is probable that the sulfur in coal will be recovered in elemental form or as sulfuric acid as new scrubbing technology develops. The use of fly ash has been the subject of considerable research, and this recovered waste may be a future source of some metals. Sludge from sewage treatment plants and food processing is being applied to agricultural land as a method of disposal with some benefits to plants from nutrients contained in the sludge. Phosphates may also be recovered from such sludge.

Many hazards to human health are now identified as contaminants in the environment. Of course, these substances usually have an adverse effect on natural ecosystems also. Leakages from the materials cycle will be subject to increasing regulation and control which will add substantially to costs of processing and manufacturing. Examples include asbestos wastes, cadmium, mercury, arsenic, and other metals, halogenated organic compounds, and particulate sulfate aerosols.

Multiple Uses of Land

The mining of raw materials, particularly at open-pit or strip mines, is encountering competition from other uses of the surface and desire for its preservation in terms of environmental quality. The purpose of state and proposed federal laws is to prevent exploitation of deposits unless the land surface can be rehabilitated and the productivity of the existing ecosystem reestablished. Aversion or repair of damage are often technically feasible at reasonable cost (*8*). However, in the arid West, the conditions for satisfactory restoration of a landscape may be so uncertain that mining is not permitted.

Other mineral resources may underlie a unique natural phenomenon or an area of such great environmental value that surface disruption, even if rehabilitation were plausible, would not be allowed. The supply of natural amenities is diminishing relative to the demand for them. This is due to a number of factors, including a growing population, affluence, and an appreciation of parks, recreation areas, and wilderness. On public lands, the very access necessary for exploration (roads, test drilling) may be limited by environmental regulations. Estimates of the practical possibilities of extracting lower grade ores where the extent of surface disruption would be widespread should be tempered by the recognition that these areas may be preempted because of their environmental value.

As abatement of point source pollution (for example, discharge of waste by a single factory) is achieved, the further improvement of water quality to meet the criteria for water contact recreation and the propagation of fish may require attention to nonpoint sources such as agricultural runoff and mine drainage. Drainage from mines, whether acidic or not, affects the quality of surface and ground waters. New underground mines may have to be engineered to minimize interference with natural aquifers and degradation of water quality. Surface subsidence is a long-term disturbance of the landscape which will be assessed as a part of the decision to proceed with new mines.

Mine wastes, mill tailings, slimes, and muds must be handled to minimize off-site effects. Underground stowage of wastes in the mine itself and stabilization of surface deposits may be required.

Materials from the outer continental shelf and the continental slope will not be recovered unless the marine environment is protected. The environmental impact assessments now under way in the leasing of oil and gas reserves and the extensive collection of marine ecosystem data sponsored by the Bureau of Land Management are the beginnings of the necessary understanding of risks to the environment from undersea technologies. A recent report (*9*) considers that there are commercial mining possibilities in the near future for sand and gravel, metal sulfides, phosphorite, heavy mineral sands, and shells on the outer continental shelf, as well as for ferromanganese nodules in the deep ocean. The environmental impacts on shore from transporting and processing these materials will be as important to plan for as those in the ocean.

Table 1. Estimates of capital costs for water pollution abatement.

Industry	Capital costs to achieve limitations (in millions of dollars)		Abatement capital expenditures as a percent of total investment in each industry 1975–1983
	1977	1983 costs in addition to 1977 costs	
Mining	3,040	0	15.2
Iron and steel	2,910	949	9.0
Pulp and paper	2,640	798	11.5
Textiles	537	300	8.3
Chemicals	4,970	4,173	16.6
Nonferrous metals	75	120	1.5
Stone, glass, and clay	75	66	1.5
Lumber	14	25	0.3
Rubber	220	48	2.0

The same report (*9*) finds that "industry must be willing to disclose data on the technology of mining pertaining to those elements of mining systems that directly intersect with the environment." Thus, some means must be devised of protecting proprietary information while adequately regulating for environmental protection. The early stage of development of ocean mining presents industry with "an opportunity to design hardware and operating methods that will minimize potential adverse environmental consequences."

The regulation of mining on the outer continental shelf will proceed from the prelease environmental impact statements required by the National Environmental Policy Act. In the international region of the deep ocean, the situation is less certain, although the federal government will probably require U.S. firms to conform to the same environmental protection regulations that would apply domestically.

The sites of large installations for processing materials or for waste disposal will be dictated by changing regulations of land use. The National Commission on Materials Policy (*1*, p. 7-1) concluded that:

> Competition for land is intensifying. Urban expansion, highways, airports, reservoirs, recreational subdivisions, etc., take up approximately 1.2 million acres every year. Commercial forest land declined 1.7 percent between 1962 and 1970. Surface mining, which produces 50 percent of our coal and 90 percent of all other minerals, is under attack. Materials production is prohibited or severely restricted on over 100 million acres of Federal land. Large additional areas are being proposed for restrictive withdrawals.
>
> Valuable deposits of sand, stone, gravel, and clay are being covered up by urban growth or zoned out of effective use. Similar impacts limit sites for recycling plants and waste disposal. Strong objections are being registered on environmental grounds against proposed new power plants, transmission lines, refineries, offshore oil drilling, deepwater ports, and other processing and transport facilities.

The enforcement of uniform standards for ambient air and water quality throughout the nation is being challenged on the basis that the natural capacity to assimilate some wastes is an economic benefit that should not be foregone arbitrarily. The concept of nondegradation of air quality might prohibit new plant construction in the locations most desirable in terms of raw materials. Variations in landscape characteristics and meteorology suggest flexibility in setting environmental goals. In some areas, materials processing industries will be limited in growth by the capacity of the landscape to accept wastes. In many large cities, if water quality standards are to be met, the disposal of wastes to water will be limited even if all practical sewage treatment is implemented. These uses of, and limits to, the assimilative capacity of the environment will add a new dimension to calculations regarding plant sites.

Conservation and Waste Management

Another recent report (*10*) states that:

> Environmental costs of materials supply, already severe, will increase still further in the absence of firm and continuing precautions, and perhaps even with them. To produce, fabricate, and dispose of wastes from ever larger quantities of metals obtained from ever leaner deposits demands ever larger investments of energy and creates growing potential for damage to all aspects of our environment on, above, and below the land surface, including living organisms. Conservational measures are needed, not only to stretch our resources but to restore, protect, and perpetuate a livable human habitat.

Environmental concerns have become important in determining the use of materials. Frequently, a coincidence occurs between the desire for resource conservation and environmental quality objectives. For example, lead is a relatively scarce metal, and its dispersion as tetraethyl lead in gasoline precludes recycling it. Now, lead additives in motor fuel are being eliminated because they poison the emissions control catalyst and are probably a risk to human health in urban areas. Aluminum from bauxite is also potentially limited in supply and requires a large amount of energy for its production. A concerted effort to recycle aluminum containers is being stimulated in the interests of reducing litter. Phosphates are an essential plant nutrient and are dispersed in agricultural practice. Their use in detergents has been decreased because of evidence that lakes receiving municipal sewage become eutrophic and deteriorate under algae growth. In such cases, conservation and environmental quality are both served.

The Committee on Mineral Resources and the Environment (*11*) concluded that:

> Efficient recycling of materials from industrial and municipal waste has become recognized as a major opportunity for conservation of materials, energy, and the environment. The greater the number of product-cycles materials can be put through the less the demand on prime resources. It is helpful to think of industrial and municipal wastes as a novel form of ore but one which is quite widely dispersed and therefore lean, especially the municipal wastes.

Recycling, unfortunately, can sometimes lead to the contamination of virgin materials. Polychlorinated biphenyls (PCB's) were, until recently, used in plasticizers and "carbonless" carbon paper that ended up in paper wastes. These chemicals are toxic to humans and other organisms and are concentrated in some fish by up to 500,000 times the amount in the ambient water. The Food and Drug Administration has set PCB tolerances for food packaging materials and various foods; the Environmental Protection Agency will probably soon set effluent standards for PCB's. Paper processing plants are finding their stock contaminated and their effluents suspect due to incorporation of PCB's from recycled paper. A materials conservation policy has backfired.

Energy, its production, conversion, and use, is the direct cause of much environmental damage (for example, recovery of fossil fuels, waste heat rejection, and combustion emissions). Regulation of these environmental consequences of energy use will have some effect on its cost and supply. As energy becomes more expensive, patterns of using it will change for those materials that require large energy inputs. Energy efficiency considerations will change processing and manufacturing technologies. For example, fuel costs will act to decrease the weight of automobiles, thus changing the quantity and type of materials in them and subsequently decreasing total automobile emissions. In this interconnected system of energy, materials, and environment, a reduction in the consumpton of energy most often will conserve materials and improve environmental quality.

Renewable resources for materials (that is, the photosynthesized products of forestry and agriculture) are receiving increased attention. Traditional uses of wood, fibers, and chemicals derived from plants may be increased and, in addition, these materials may be substituted for mineral resources. The renewable resources are produced in heavily managed ecosystems that illustrate a unique set of interactions with environmental quality. Agriculture represents a nonpoint source of pollutants such as fertilizers, pesticides, sediment, and feed lot wastes. Forestry practices, such as clear cutting, are regulated for erosion control and esthetic considerations. Conversely, these managed ecosystems are adversely affected by other pollutants, particularly airborne contaminants such as ozone and sulfur dioxide. The increased acidity of rainfall, due to air pollution, can damage trees and crops and increase the mobilization of minerals from the soil. This set of environmental problems is, of course, little different from that encountered in agriculture for food production. However, any substantial increase in renewable resources for materials should take into account the associated environmental impacts.

Summary

The tensions between availability of materials and quality of the environment will increase with economic growth and the appreciation of environmental values. These tensions can be relieved to an extent by internalizing the costs of environmental protection so that they are reflected in the price of materials. Economic incentives and disincentives, such as effluent fees, are receiving renewed attention (*5*, pp. 49–51). In addition, government regulation to protect the environment will, perhaps arbitrarily, affect the availability and use of materials. The report, ***Man, Materials, and Environment*** (*5*, p. 25), concluded that:

> A national materials policy should be based upon the principle that calculations of benefits and costs associated with the extraction, transport, processing, use, and disposal of materials should take full account of the value of common property resources and of any change in the value of common properties resulting from the impact of materials on the environment; and should support the principle that those responsible for impairment of the environment should bear the costs of damage or repair. These principles should become a commonplace element of property rights, legislation, and administrative practice at all levels of government. The difficulty of measuring benefits and costs should not delay adoption of these principles but suggests the need for continuous observation and experimentation.

Environmental protection regulations will result in: (i) increased costs for many materials; (ii) disruptive changes in use of materials, due to environmental characteristics and revised cost effectiveness calculations; (iii) restrictions on the siting of processing and manufacturing installations; (iv) preemption of access and surface rights to some mineral bearing lands, particularly those that are federally controlled; (v) diversion of capital from new production facilities; and (vi) frustrating delays in decisions, such as those affecting leasing and plant siting.

In return for these generally undesirable disruptions in the continued development and supply of materials, society will obtain: (i) improved quality of air and water; (ii) long-term protection of the natural ecosystems of which man is a part; (iii) more efficient allocation of natural resources on the basis of more accurate and complete accounting of costs; (iv) improved human health through decreased contamination of the environment with toxic substances; and (v) conservation of materials through a closing of the production, use, and disposal cycle.

Ingenuity and a more complete understanding of the parts and interactions of the energy, materials, and environment system can do much to reduce the tensions in these conflicts and bring about equitable trade-offs among societal goals.

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