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# Mineral Resources: Challenge or Threat?

## Can technology meet our future needs for minerals and still preserve a livable environment?

Walter R. Hibbard, Jr.

For I dipt into the future,
far as human eye could see,
Saw the Vision of the world,
and all the wonders that would be;
TENNYSON, *Locksley Hall* (1842)

Soothsayers are popular when they foresee good things and predict fulfillment of widespread longings and expectations. Consequently, Edward Bellamy's utopian novel, *Looking Backward*, was a best seller when it appeared in 1881 (*1*). It foretold that in the year 2000 there would be a very good thing in Boston—an ideal society.

Those who foresee dangers and darkness are less likely to be listened to. Cassandra predicted that Troy would fall, and no one believed her. Malthus reasoned that population would outstrip food supply, and all kinds of refutations were marshaled against him. Lindbergh in 1938 warned that the air force which the Nazis possessed was the best in the world, and he was doubted.

It is the same today. We tend to ignore predictions of bad news. We respond to alarms only when the house is already on fire.

Bellamy, whose book is enjoying a modest revival now, believed that it would be "the limit of human felicity" if people could have "music in their homes, perfect in quality, unlimited in quantity, suited to every mood, and beginning and ceasing at will" (*2*). This describes the phonographs and stereo tape recorders now in many American and European homes.

Many of today's and tomorrow's problems also have long been predicted, but we are accustomed to undertake seriously and purposefully solutions to only those problems that present a clear and immediate danger. Too often solutions come too late, and it becomes necessary to apply remedies which are expensive and difficult; the answers would have been cheaper and easier had we started earlier.

Thus, in a society whose standard of living is the highest ever attained for so many people, the opinion that our economic growth may decelerate and our living standard decline would be highly unpopular.

### Let Science Fix It

We are called an affluent society, and we want to believe it; but is it really true? Secretary of the Interior Udall has called our vaunted superabundance a myth inherited from the 19th century. And this myth is rapidly being supplanted, he says, by a "myth of scientific supremacy . . . we tolerate great imbalance" in the use of our natural resources and "shrug off the newer forms of erosion with a let-science-fix-it-tomorrow attitude" (*3*).

Our ability to handle some of our greatest present threats—war, poverty, crime, urban crowding and ugliness, growing damage to our environment—is seldom thought of as resource-limited. Whatever material resources we need to solve these problems, most of us apparently assume are already here at hand—or if not, don't worry; the economics of the market place will soon provide them!

A requisite for affluence, now or in the future, is an adequate supply of minerals—fuels to energize our power and transportation; nonmetals, such as sulfur and phosphates to fertilize farms; and metals, steel, copper, lead, aluminum, and so forth, to build our machinery, cars, buildings, and bridges. These are the materials basic to our economy, the multipliers in our gross national product. But the needed materials which can be recovered by known methods at reasonable cost from the earth's crust are limited, whereas their rates of exploitation and use obviously are not. This situation cannot continue.

A warning to that effect was sounded early in the last decade by the President's Materials Policy Commission after a careful review and appraisal of our materials balance sheet (*4*). The report, *Resources for Freedom*, popularly known as the Paley Commission Report, was published before the full impact of the current population increase was widely recognized, and before the full extent of the postwar expansion of the U.S. economy was identified. Therefore many of its forecasts of mineral supply and demand turned out to be too conservative, too comforting. The commission has been widely criticized for not sounding the alarm. Its cautious conclusions have been questioned—and largely ignored or forgotten.

Although there were obvious inconsistencies between their forecasts and subsequent events, the philosophy that underlay the Paley Commission study was sound, and its general conclusions apply today as much as they did 15 years ago. In area after area the

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same pattern was discernible: soaring demands, shrinking resources, the consequent pressure of rising real costs, the risk of wartime shortages, the ultimate threat of an arrest or decline in the standard of living we cherish and hope to help others attain.

Last year, President Johnson, in a message to Congress on air pollution (*5*), summed it up in another way.

Sharply rising world demands threaten to exhaust the best and most accessible deposits of minerals. Rapidly changing demands for materials are bringing changes in our mineral needs. We must understand the technological and economic changes taking place.

**Severe Strain on Mineral Supply**

With only about 9 percent of the Free World population in 1965, the United States consumed between 30 and 40 percent of the Free World's mineral supply (*6*). Simple projections based on growth of the population and the gross national product suggest that by 1980 consumption of minerals by the United States will in general increase by 50 percent and in many cases double. Although by 1980 it is estimated that the United States will include 7.7 percent of the Free World's population, the number of people in the nation will increase by some 29 percent, and the Free World's population is projected to increase by 50 percent. This sheer weight of numbers is going to place a severe strain on the mineral supply of the Free World to maintain and improve the standard of living in most of the Free World.

With the rapid expansion of the economy during and since World War II, the United States has consumed a correspondingly large increase in mineral output. The result has been greater dependence of U.S. industry on foreign sources of raw materials. Today, imports supply over 75 percent of our needs for 20 different mineral commodities (*6*). Also world mineral development and depletion of the higher grade domestic reserves and development of mineral industries in other nations have led the U.S. mineral producer into widening world competition for key resources.

Recognizing our increasing reliance on foreign resources, the Paley Commission recommended: (i) government measures to encourage investment of risk capital in the mineral industries; (ii) a continuous appraisal of the nation's mineral and energy supply position; and (iii) accelerated research and development to expand the base of our mineral and fuel resources.

These recommendations are still valid. Indeed, events since the Paley Report make it more urgent than ever to expand the technical and economic base of our resources by every feasible means.

**New Paley Commission Study Urgent**

Industrial growth in many parts of the world, the population explosion, advances in transportation and in communications, changing marketing patterns, shifting needs and requirements stemming from wars (Vietnam and the Middle East), and the emergence of new nations—all these, and other trends barely discernible now, make it imperative that another study similar to the Paley Commission review be made as soon as possible so that we may anticipate and undertake as soon as possible the steps necessary to avert serious calamity. Although such a study may also fail in precision of forecasting, new and continuously revised estimates of each mineral requirement and each type of fuel or energy source would provide a sound basis for action by both government and private industry.

Raw materials are powerful economic multipliers. Cost changes in ores are reflected throughout the economic structure, from metal producer, to fabricator, and ultimately to the consumer. But we cannot depend upon the law of supply and demand in a free economy to spur the necessary investment. Mineral production cannot be turned on like a faucet. Substantial capital (hundreds of millions of dollars per venture) and substantial time (often 5 to 10 years) are required to complete a new mineral-producing facility.

**The Time Problem**

Prain points out that the mining investor has to wait many years, perhaps a quarter of a century, before a mine can be built and can operate long enough to repay his investment and make a reasonable profit (*7*).

Winning from the earth the minerals needed for prosperity and well-being depends not only on the capital available for investment, but also on the technology that can be applied. As Boyd has pointed out, our resources are limited less by the amounts of raw materials than by the technology of treatment and extraction and by the capacity to produce at a reasonable cost (*8*). Spencer believes that one mineral industry, petroleum, will be "bumping against the ceiling, not of resources, but of technology, and therefore of capital. Unlike land, which becomes more valuable as population increases and good prospects are snapped up, technology can be improved, and the supply of capital can be stretched" (*9*).

Although technology may stretch capital by less-expensive production facilities, permitting utilization of lower grade ores, only long-range planning can remedy the time problem. It is already too late to initiate new production capability for 1970; facilities for that year must be well along in development now.

Technology, willingness to risk capital, and planning have made the United States a major producer of minerals. The U.S. Bureau of Mines shows complete world production data on 54 mineral commodities for 1966 (*10*); U.S. led in the production of 27. In the case of 11 additional commodities for which complete figures were not available, it is believed the United States led in the production of six.

However, as long as mineral deposits in other parts of the world can be profitably developed, the incentives for radical innovation in technology are slight and investment capital is attracted abroad. It is axiomatic that investors seek out ventures that are the most profitable. Hence, capital will flow to those countries with lower labor costs, greater government incentives (such as tax benefits and subsidies), and minimum costs for pollution control (relative to the United States) as well as high-grade reserves which can be readily exploited by well-established procedures and available equipment. Already, American investment in mining is going abroad at an increasing rate—to Australia, Canada, Spain, South Africa, and South America. If this trend continues, by 1985 we may be importing a major portion of our large-tonnage metals such as iron, copper, lead, and zinc, thus adding commodities for which the United States is already primarily dependent on overseas sources. Advanced technology at home, economically applied to domestic reserves, can reverse this trend.

## Technology Can Expand Resource Base

Most of our mineral industries are mature; they have been operating for a long time, and the cream has been skimmed from the richest and most easily recovered ores. Yet technological innovation is continually injecting new life into these mature industries. I believe that technology can help increase our mineral resource base in the following four ways:

1) Exploration and discovery. The minerals so far used by man have come from very near the surface. Most were discovered from outcrops. We must learn how to explore at depths, and we must develop methods to find and extract minerals in the deeper layers of the earth's crust and from under the sea.

2) Improved mining, beneficiation, and processing. More efficient methods for mining ores and for upgrading them before smelting and refining can make the use of leaner ores technically and economically feasible.

3) Recycling of scrap and waste. There is tremendous opportunity in "mining" our scrap heaps and junkyards. Already about 40 percent of this year's production of lead and 25 percent of this year's copper comes, not from primary ores, but from reclaimed scrap. Such salvage programs could be greatly extended through research and improved collection and processing techniques.

4) Substitution. Using abundant materials in place of those in short supply is the challenge of the physical metallurgist—and of the polymer chemist. Not only is there strong economic pressure to find substitutes (because they are usually cheaper), but there is technical pressure also. The materials engineer, redesigning from basic principles, often finds that the traditional materials are not the best technically.

Potentially one of the most rewarding opportunities for dramatic expansion of our mineral resource base—and one of the greatest challenges to our ingenuity—is the exploration and exploitation of the almost untapped three-quarters of the earth's crust beneath the oceans (Fig. 1). The deepwater sections are beyond our reach at present, but very encouraging progress has been made on the continental shelves, defined as offshore sea bottom to a depth of 200 meters. These shelves are geologically similar to the adjacent dry land; and we can assume with some confidence that they contain ore bodies of similar types and distributions.

Let us imagine a map of the United States with a 200-meter depth line offshore, showing the approximate extent of our 2.3 million square kilometers of continental shelf. If we were to flip the shelf over onto dry land, using the coast line as a hinge, we would have a mirror image of the shelf. The value of the minerals produced from this onshore mirror image is estimated at $160 billion (in 1966 dollars), exclusive of the value of the oil and gas produced.

It is entirely reasonable to expect several billion dollars worth of minerals in our continental shelf, but we must develop the technology to explore, identify, and sample them; and then the technology of delineating and mining these undersea deposits. About 60 percent of the shelf area has a thick cover of sediment; 20 percent is believed to have a thin cover; and another 20 percent to be essentially bare bedrock or outcrop.

## Invisible Gold

The technology of improved exploration and processing is typified by recent developments in gold production. Gold has traditionally been discovered in visible deposits, where material can be crushed and physically separated by panning. Extracting the ores from a wide variety of geologic settings, at varying ocean depths in all kinds of weather, is a formidable challenge requiring new technology. Elemental gold can generally be picked out because it is

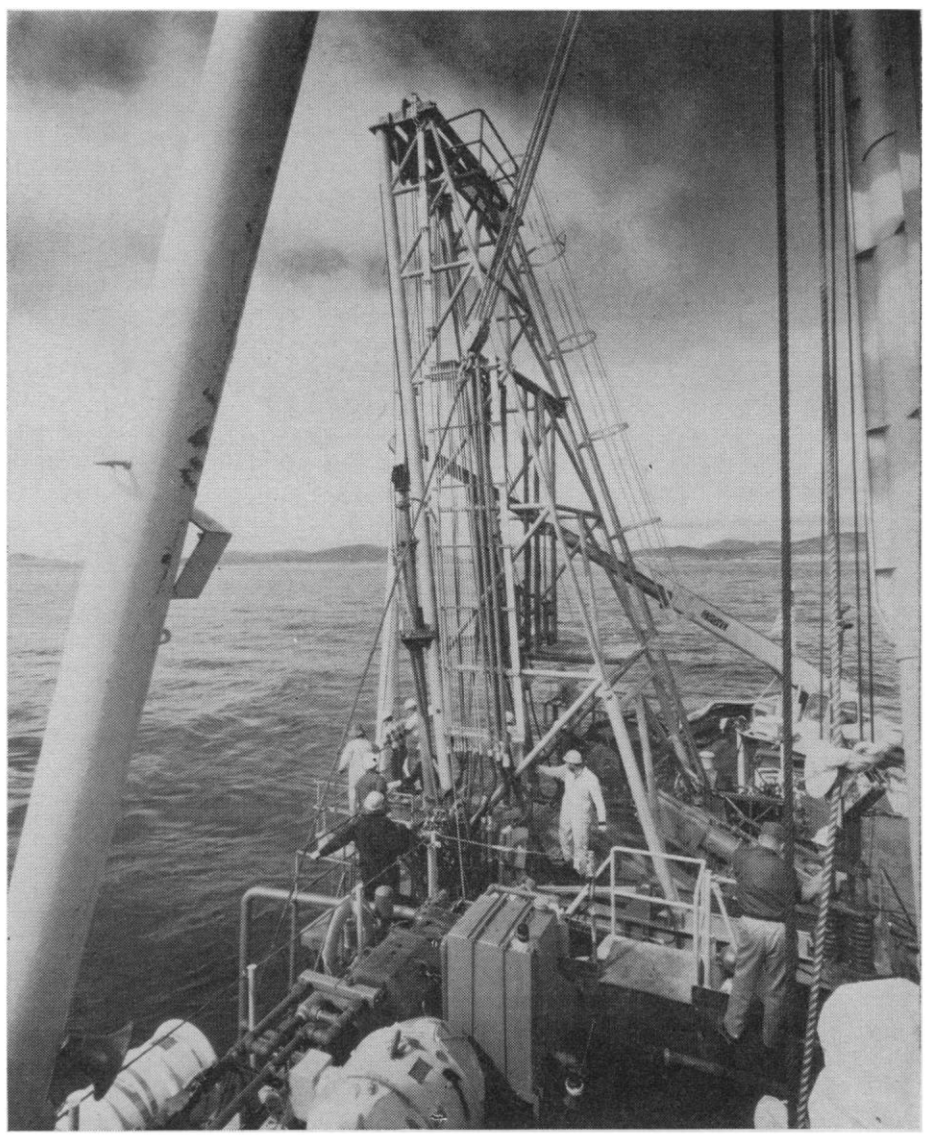

Fig. 1. The *Virginia City*, research vessel of the Department of the Interior, takes core samples from sea bottom off Nome, Alaska, in tests of new equipment and methods for undersea sampling and mining.

Fig. 2. Close-up of Kennecott's Kimberly copper mine at Ely, Nevada, shows how terraces serve as roads for the ore trucks.

heavier than other minerals in the mix. So-called invisible gold, identified only by sophisticated chemical analysis, has been discovered. One such discovery, at Carlin, Nevada, was largely responsible for the 1965 increase in U.S. gold production.

Chemical extraction of gold from ore is also being improved, supplanting methods that are 50 years old. With massive new techniques for bulk ore-handling, low-grade ore deposits known as dry placers may be surface mined.

Thus, discoveries (including anticipated development of offshore gold placers in the estuaries of once-productive gold-bearing stream and beaches), better mining, and progressive technology should ultimately make it possible to increase U.S. gold production three- or fourfold.

Recycling to further extend our resource base is certainly not a new concept; it is an established business of great social usefulness and should not be deprecated as junk. Most of its value is in metal scrap. Even in our disposable, no-deposit-no-return, throw-away mode of living, sales of nonferrous scrap alone amount to $1.5 billion annually. This figure represents only that portion of recycled nonferrous metals that go through obsolescence, discard, and scrap dealers; it is only a fraction of the total, for home scrap produced in metal and fabricating plants is recycled without going through the scrap dealer and its value cannot be accurately computed.

Two reforms are urgently needed to extend the use and to expand the reuse of valuable materials, even though they may seem to run counter to the affluent status our society seems to be trying to maintain. (i) We should design our durable, mineral-containing products to last longer before they go out of style or wear out, and (ii) we should design such products to make it easier to collect and separate their mineral content for recycling after they are discarded.

An American automobile, for instance, lasts about 7 years, or 160,000 kilometers. From a technical standpoint, doubling those figures should not be difficult, and there would be a tremendous saving in metals and other materials.

Moreover, most automobiles seem to be designed on the assumption that no one, not even a mechanic, will ever want to take one apart. Workers at the Bureau of Mines have dismantled several dozen cars of different ages and makes in the course of current work on solid-waste disposal problems. The manufacturers were unable to tell them the composition and distribution of materials in their cars, since many components were supplied by vendors. The placement of these components and the overall design of the car are subject to many restrictions: conservation of space, esthetic appeal, ease of manufacture, safety, and others. The result is that not only the exterior design but also the materials which are used in automobiles change from year to year. Wiring becomes more complex in order to take care of additional electrical equipment. Increasing use is made of stainless, aluminized, and galvanized steel and of aluminum and zinc castings and other materials which make salvage difficult.

I propose that in designing automobiles—and refrigerators, ranges, and other metallic consumer products—manufacturers should provide greater durability, retard obsolescence, and anticipate the need for recycling. If engineering design were to include this concept, valuable materials could then be readily saved when the product is obsolete or worn out. This is a stiff requirement but a necessary one. The annual addition to the scrap market of millions of tons of metal is such a valuable potential resource that we cannot afford to overlook any means of making it easier to salvage.

The continuing failure, on the one hand, to retard the flow of usable materials into the scrap piles, and, on the other hand, to utilize this above-ground bonanza more fully to satisfy our proliferating requirements is shortsighted, in fact, criminal.

There is no reason why, with skill in design and materials application, we cannot make products more durable while we salvage every bit we can from our unusable and discarded products, and thereby extend the mineral resource base of the nation.

The rising need for minerals creates the corollary problem of controlling the detrimental effects of mining on man's living space and on his environment. The same increases in population and living standards that require more minerals also require intensified and multiple use of land for homes and other buildings, for roads and airports, for parks and recreational areas.

## Mechanical Monsters at Work

Our current mining operations, for reasons of economy, are, where feasible, conducted from the surface rather than underground. These open-pit, strip or surface mines (Fig. 2) already produce most of the tonnage of some materials such as copper, and in the foreseeable future will extract an even larger proportion of coal and ore in the United States. Big machines—large electric shovels and draglines, some of which can handle up to 152 cubic meters at a single pass and cost as much as a jet plane—are making it profitable to mine deposits under a considerable overburden of earth and waste rock (Fig. 3).

But mounting public protests against alteration of the land surface (Fig. 4) and the past failure of numerous operators to restore mined lands to satisfactory condition may reverse the trend. Several states already have passed or strengthened their strip-mining laws and enforcement procedures. Other states—and possibly the federal government—may also take action along these lines. These measures will obviously add to the costs of surface-mining operations and can shrink the available resources. Marginal producers may be discouraged, but the necessities of the situation will stimulate more economical and efficient mining and transportation techniques.

In addition, there are finite limits to deposits minable by surface access. Consequently there is an urgent need to develop more efficient underground mining equipment, analogous to the gigantic, economic, high-speed surface machines concurrently with new systems of procedures and techniques for high-capacity underground operations. Some equipment has already been developed (such as the giant boring machines) to bore vertical holes as large as 2 meters in diameter in soft rock; and horizontal holes up to about 13 meters in diameter (Fig. 3). Such machines can chew their way along at satisfactory speeds, but the broken rock and ore pile up too fast to be removed by present conveyor systems. Other problems are proper ventilation at a rapidly moving cutting face, fast and efficient propping to keep the tunnel intact, means of handling water intrusion, and methods of geological reconnoitering to locate obstacles or hazards before the cutter reaches them. All of these challenges await technical solutions which I believe the future burgeoning demands for minerals will bring about.

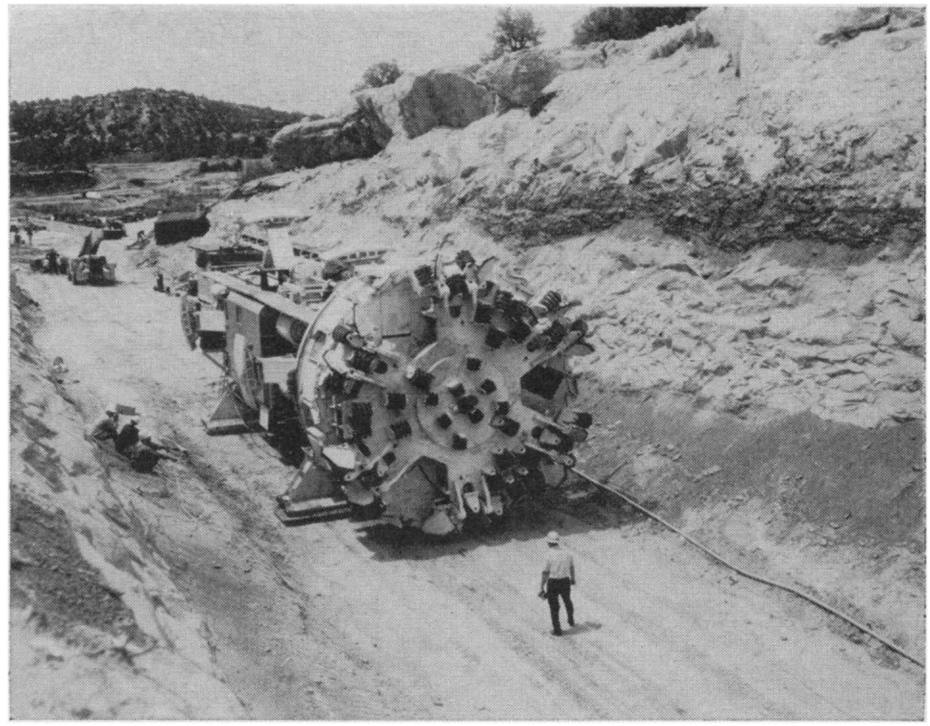

Fig. 3. Continuous, mechanized equipment to mine deeply buried ores economically in the future may resemble this 5-meter boring machine, linked to extendable conveyors to remove the broken ore.

## Rapid Excavation for Urban Development

Incidentally, development of rapid tunneling methods would benefit many aspects of modern life other than mining. Subway systems and vehicular tunnels would be easier and cheaper to build. Greater portions of our water, sewer, electric power, and communication systems could be installed underground. Buildings in metropolitan centers might grow downward as well as upward, thereby creating new living and working space.

Our increasing need for minerals has created the additional environmental problem of air pollution, largely the result of the burning of fossil fuels and the processing of minerals, which adds to our costs. If their emissions are not carefully controlled, coal-fueled electric power stations, steel mills, and other industrial plants pour sulfur oxides and fly ash into the air. Automobiles, trucks, and diesel-powered vehicles produce hydrocarbons and nitrogen oxides. All fuels produce carbon dioxide—in itself harmless and necessary for plant life,

Fig. 4. Kennecott Copper Corporation's open-pit mine at Bingham Canyon, Utah, is one of the world's largest mining excavations. Another view is shown on the cover.

but potentially harmful if it should accumulate enough to change the world's atmospheric composition. Imperfectly burned fuel produces carbon monoxide, a deadly poison. Awareness of the hazards of these pollutants to people, animals, and crops is bringing about laws and regulations that upset normal patterns of fuel use. Consequently, the cost of air-pollution control increases the costs not only of power production, space heating, and manufacture, but also that of fuels treated or modified to meet new standards.

### Technology of Air-Pollution Control

In general, the technology of controlling air pollution is known. Many government agencies and industry are working on these problems, but, in every case I know of, the cost is still too high for voluntary adoption by the industries involved. People must be educated and their habits changed. The social force of public opinion, backed by legislation when necessary, is needed before much progress can be made, and research and development work must be continued and expanded.

Work on one aspect of air pollution at the U.S. Bureau of Mines points to the encouraging prospect of getting valuable products from the poisons taken from air. A process used by the Bureau to remove sulfur dioxide from the stack gases of coal-burning plants recovers part of the process cost from the sale of elemental sulfur. The prospect of using a crop-killing pollutant to make fertilizer is intriguing. Technology to control air pollution is also being applied to the fuels themselves, as in the removal of sulfur before burning. These developments as well as legislation, regulations, and social pressure will have a bearing on the kinds of fuels we use and on their costs. Will we have enough of the prescribed kind to meet our needs in the future?

Disposal of trash and other solid waste is nearly as acute an environmental problem as the pollution of air and water. We pay dearly for space in which to dump discarded material that may contain valuable metals. We bury in sanitary landfills tons of iron and other metals mixed together in residues from municipal incinerators. Even as we bury metal in one place we are looking elsewhere for ores that may well be leaner than our sanitary landfills.

### Bonanza in the Trash Heaps

The 34 million metric tons of municipal refuse incinerated annually in this country contain more than 2.8 million metric tons of iron and some 180,000 metric tons of aluminum, zinc, copper, lead, and tin (*11*). Archeologist-miners of the future may well go prospecting in our city dumps, which for the present are lost resources.

The disposal, control, and reclamation of mineral waste products also pose technologic and social problems, and in addition are economic factors in the effective conservation and use of mineral resources. The problem must be attacked from the standpoint of conservation by minimizing the amount of waste produced. Specifically, methods must be sought to improve recovery systems in order to reduce mineral losses and to reduce the volume of products finally discarded. In addition, more efficient techniques must be devised for reclamation and reuse of mineral-based materials that currently are wastefully discarded—a practice we may no longer be able to afford.

We should develop the technology to mine waste of all types. Recovering metals and other minerals from mine tailings, industrial refuse, and incinerator ash are likely places to start.

Of course, these objectives in themselves do not provide adequate direct economic gains to industry. On the contrary, they would frequently add costs that would probably have to be passed on to consumers. Nevertheless, the problems arising from mineral supply cannot be treated apart from environmental degradation stemming from the mining, treatment, or use of any mineral substance.

In our political and economic system, it is the responsibility of private industry to develop and exploit resources to meet demands at the market place. It is the federal government's role, however, to assume a position of leadership in determining the projected needs, in supplying the long-range scientific and technologic support for the minerals industry, and in using techniques such as education, communication of information, and cooperation to encourage industry to attack the vital problems of minerals supply. Such assistance is especially necessary where the risks are too costly to be undertaken by a corporate entity, and where the rewards benefit the public rather than a particular industry. Research and engineering are under way to devise methods for processing marginal reserves, improving efficiency of extraction and recovery, recycling mineral materials, and making alternatives or substitutes for mineral materials in short supply.

All these efforts of the government are aimed at promoting the wise development and use of the nation's mineral resources to sustain the economy and to assure adequate, dependable supplies at the lowest economic and social cost. But these efforts, with those of cooperating state and local governments and the mineral industries, are not enough. A broad public understanding is needed to insure support for the concerted action by all sectors of our society to alleviate the coming threats to our mineral resources.

### Understanding by Scientific Community

Understanding by our scientific community is especially needed, for, although I have stressed the technical and utilitarian aspects of the problems we will face, there is a tremendous need for scientific backup. The challenges herein are not just to engineers, industrialists, and statesmen: they are as well to scientists of many disciplines; for, unless we acquire the fundamental knowledge to apply, our progress may be too slow to avert the threats to our standards of living and future security.

These threats—or challenges—can be summed up. (i) Minerals are essentially and in the long run nonrenewable, and some of our mineral reserves, exploitable by today's technology, are becoming exhausted. (ii) The population explosion and rising living standards impose unprecedented demands that will hasten the depletion of our mineral resources. (iii) Pollutants from the extraction and use of minerals and the sheer bulk of inert wastes are degrading our environment and must be controlled, even at increased real costs for the minerals we need. Whether these predictions are optimistic or pessimistic depends upon one's temperament and point of view. I believe they are optimistic, that the tasks we face are demanding, but not impossible.

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# Sense and Nonsense in the Genetic Code

## Three exceptional triplets can serve as both chain-terminating signals and amino acid codons.

Alan Garen

The recent elucidation of the genetic code, shown in Table 1, marks a notable milestone in biology (*1*). This code designates the relations between the 64 possible codons (*2*) present in messenger RNA and the 20 amino acids present in proteins. The RNA codons are derived by transcription of complementary codons in DNA, which is the primary genetic material of most organisms (the only exceptions known are certain viruses in which messenger RNA is used directly as the genetic material).

Most of our present knowledge about the code has been obtained from studies with *Escherichia coli*, in which synthetic polyribonucleotides (rather than natural messenger RNA) are added to cell extracts containing the components required for protein biosynthesis in vitro (and presumably in vivo) (*3*). The polynucleotides in such experiments are either triplets, which can bind a specific transfer RNA species to ribosomes, or longer chain polymers (with random or defined base sequences), which can direct the incorporation of amino acids into polypeptides. A critical assumption for this approach to the deciphering of the code is that the coding properties of polynucleotide codons in vitro are the same as those of messenger RNA codons in vivo, allowing the extrapolation from in vitro to in vivo coding assignments. There is convincing support for this assumption from two lines of evidence, one showing that amino acid substitutions occurring in proteins as a result of mutations can be attributed to base changes which are consistent with the coding assignments for the amino acids (*4*–*6*), and another showing that the RNA component of an RNA phage acts in vitro as well as in vivo as a messenger for the coat protein of the phage (*7*). It should be noted that a coding assignment based on results in vitro does not necessarily prove that the codon is actually used in vivo; there is evidence that an organism can have the capacity to translate a codon but not incorporate it into its own code (see *6*).

It is implicit in a triplet code, which provides a potential surplus of triplets for 20 amino acids, that the code contains degenerate codons (that is, different triplets coding for the same amino acid) or nonsense triplets (triplets which do not code for any amino acid), or both. It is immediately apparent from a glance at Table 1 that the code exhibits extensive degeneracy, as much as sixfold for some amino acids. There also are three triplets, UAG, UAA, and UGA, designated as nonsense, and it is this aspect of the code which is the main subject of this review.

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### Nonsense Mutants

Protein biosynthesis is a sequential process during which a peptide chain grows unidirectionally, by increments of one amino acid, from the amino-terminal toward the carboxy terminal residue (*8*). Accordingly, if a nonsense triplet is present at any of the positions in messenger RNA which code for the amino acid residues of a peptide chain, a gap will appear in the chain and cause premature termination of chain growth. Nonsense triplets do not normally occur within the coding regions of messenger RNA, but they can be generated from certain codons by mutation. The resulting mutants are called nonsense mutants, as distinguished from missense mutants which result from the transformation of a codon for one amino acid into a codon for another amino acid.

Since nonsense mutants cannot be produced selectively, a procedure is required for their identification in a population that may contain other classes such as missense, frame-shift, and deletion mutants. The problem can be simplified to some extent by restricting attention to mutants that can be reverted to the parental type by exposure to the base-analog mutagens 2-aminopurine or bromouracil (*9*); these mutants should comprise only the nonsense and missense classes.

To distinguish nonsense mutants from missense mutants, four procedures have been used with bacteriophage and bacteria. Evidence obtained by these procedures has firmly established the existence of nonsense mutants and has confirmed the hypothesis that the mutants produce chain-terminating nonsense triplets. The experimental details are as follows.

1) *Pleiotropic mutant phenotype.* Because of the polarity of messenger RNA, which is translated unidirectionally starting from the 5′-end of the molecule (*5*), it is possible for one nonsense triplet to block translation of an extended region of the RNA molecule. The extent of the block will depend on