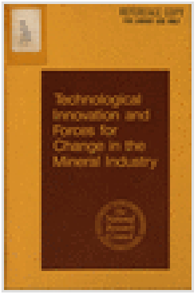

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This report is an examination of the status and present role of technology in the mineral industry, an assessment of the constraints to technological innovation in the industry, and an inspection of the forces that are increasingly affecting mineral operations. The report notes that although the mineral industry relies on technology to a large degree in converting resources to usable energy and mineral forms it does not base its competitive position on technology but rather on control and access to the best available deposits. These deposits may be large-volume/low-grade bodies or they may be relatively smaller but high-grade concentrations of mineral materials. After reviewing the status of mineral technology, barriers to technological innovation, and the forces for change in the mineral industry, the report concludes that not only is new technology needed but there should be a special federal government effort to seek ways of encouraging technological innovation in the domestic mineral industry. Particularly needed is a federal policy and the establishment of federal programs with incentives for enhancing the technological capability of the domestic mineral industry.

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Technological Innovation and Forces for Change in the Mineral Industry

A Report Prepared by the Committee on Mineral Technology

Board on Mineral and Energy Resources
Commission on Natural Resources

National Research Council

NATIONAL ACADEMY OF SCIENCES
Washington, D.C. 1978

NOTICE

The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the Councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the Committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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COMMITTEE ON MINERAL TECHNOLOGY

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College of Mines
University of Arizona

MINING PANEL

Chairman: Rudolf Kvapil
Golder Associates

Charles Fairhurst
Department of Civil and Mineral Engineering
University of Minnesota

Thomas E. Howard
Joy Manufacturing Company

Kenneth E. Mathews
Department of Mining Engineering
University of British Columbia

Ernest L. Ohle
Hanna Mining Company

Lee W. Saperstein
Department of Mining Engineering
Pennsylvania State University

Galen G. Waddell
U.S. Bureau of Mines
Twin Cities Mining Research Center

Alfred Weiss
U.S. Bureau of Mines
Washington, D.C.

METALLURGY PANEL

Chairman: John F. Elliott
Department of Metallurgy
Massachusetts Institute of Technology

Jagdish C. Agarwal
Ledgemont Laboratory
Kennecott Copper Corporation

Frank A. Aplan
Department of Material Sciences
Mineral Processing Section
Pennsylvania State University

Nathaniel Arbiter
Natural Resources Group
The Anaconda Company

Douglas W. Fuerstenau
Department of Materials Science and Engineering
University of California, Berkeley

Thomas A. Henrie
U.S. Bureau of Mines
Washington, D.C.

Carl Rampacek
Mineral Resources Institute and State Bureau of Mines
University of Alabama

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* The Board on Mineral Resources, under whose auspices this Study was carried out, was combined with the Board on Energy Studies late in the course of the project to become the Board on Mineral and Energy Resources.

WORKSHOP PARTICIPANTS

MINING PANEL

Thomas E. Howard
Joy Manufacturing Company

Rudolf Kvapil
Golders Associates

Kenneth E. Mathews
Department of Mining Engineering
University of British Columbia

Ernest L. Ohle
Hanna Mining Company

Lee W. Saperstein
Department of Mining Engineering
Pennsylvania State University

Galen G. Waddell
U.S. Bureau of Mines
Twin Cities Mining Research Center

METALLURGY PANEL

Jagdish C. Agarwal
Ledgemont Laboratory
Kennecott Copper Corporation

Douglas W. Fuerstenau
Department of Materials Science and Engineering
University of California, Berkeley

Herbert H. Kellogg
Henry Krumb School of Mines
Columbia University

Ralph C. Kirby
U.S. Bureau of Mines
Washington, D.C.

Peter T. Luckie
McNally Pittsburg Manufacturing Company

Frank W. Luerssen
Inland Steel Corporation

Terence P. McNulty
The Anaconda Company

AT LARGE PARTICIPANT

W.H. Clive Simmonds
National Research Council of Canada

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"Unlike resources found in nature, technology is a man-made resource whose abundance can be continuously increased, and whose importance in determining the world's future is also increasing."

Chauncey Starr

PURPOSE, ORGANIZATION, AND OPERATION OF THE COMMITTEE

In view of the threat of potentially serious problems now surrounding the acquisition of mineral raw materials, it is appropriate to review the status of mineral resource technology in the United States.[1] With this goal in mind, the former Board on Mineral Resources of the National Research Council formed a committee to: (1) review the status of mineral resource technology as it pertains to our capability for expanding domestic mineral production, (2) determine what constraints, if any, to technological innovation may exist, and (3) recommend programs and areas of activity where technological knowledge might be used to contribute to an improvement of our domestic mineral supply position. It has not been the purpose of the Committee to make an inventory of specific deficiencies in mineral technology nor has it been the purpose simply to list recommended topics of research in this area. Rather, it has been the purpose of the Committee to determine what is needed to foster the development and use of new technology in the mineral industry. This report is concerned with the findings of the Committee with regard to the status of technology and the constraints to technological innovation in the mineral industry. It also examines forces that may bring about notable changes in future mineral industry operations. It does not address the problems of crude oil, natural gas or water as these topics are receiving consideration in a variety of Academy, government, and other studies.

In forming the Committee on Mineral Technology it was the intent of the Board on Mineral Resources to involve a balanced distribution of representatives from the three sectors concerned with mineral technology, namely, industry, government and academia. The Committee was divided into two panels--a mining panel chaired by Dr. Rudolph Kvapil and a metallurgy panel chaired by Dr. John F. Elliott. The metallurgy panel was designed to include both mineral beneficiation and extractive metallurgy in its responsibility.

The Committee fully realized that new developments in mineral technology are but one of several ways to avert or minimize future shortages because such developments apply only to the supply side of the supply/demand equation. Efforts to reduce demand for mineral commodities through conservation efforts and efforts to improve the supply of raw materials by the fuller use of recycled materials are other avenues of approach which also involve technology and which also should be pursued with equal vigor if future shortages or external pressures are to be minimized or averted. Additionally, there are other factors such as tariff protection, subsidies, income tax deductions, and price controls which also provide incentives or restrictions on technological innovation. However, these subjects were not considered to be in the purview of this committee. It was recognized by the Committee that a part of the supply problem is our inability to readily locate mineral deposits which are not demonstrated through outcroppings or are not sufficiently close to the surface to display anomalies to physical measurements. Clearly, new technology is also necessary for application in the area of mineral exploration. However, as one committee member pointed out, "...it is well to remember that some of them (ore deposits) in the past have not so much been found by geologists as they have been created by metallurgists or mining engineers." In other words, new technology, applied by mining and metallurgical engineers has made it economic to produce mineral materials that would not have been considered to be ore if the new technology had not been developed. This concept of "creating" ore deposits was foremost in the Committee's thinking as it investigated and appraised the current status of mineral technology in the United States.

The main activity of the Committee was a workshop meeting held at the National Academy of Sciences in Washington on February 7 and 8, 1977, at which time invited speakers, chosen by the panels to represent expertise and experience in the various subcategories of each panel, gave their views of the status and needs of mineral technology in their area of specialty. Each speaker was asked to address himself to a series of outline questions as follows:

1. Is current technology adequate to meet America's mineral raw material needs in the future?

(a) near term (b) mid term (c) long term

2. What new technology is needed:

(a) to increase the recovery from mineral deposits we now rely upon?

(b) to begin the effective utilization of less conventional mineral deposits such as: low-grade, refractory, and deep or remote deposits?

(c) to reduce capital investment requirements?

(d) to improve the decision-making tools used in selecting investment alternatives?

3. How effective are present practices in bringing R&D results to industrial utilization?

4. What constraints exist to:

(a) the development of improved technology?

(b) the utilization of improved technology?

5. What motivations exist to:

(a) the development of improved technology?

(b) the utilization of improved technology?

6. How might government, industry, and academia be helpful in improving U.S. mineral technology? What roles for each might be recommended?

This report represents the distillation of the contributions of the workshop participants together with the results of the deliberations of the Committee.

In a subsequent activity, the Committee on Mineral Technology is preparing to address itself to specific ways by which the federal government, acting in concert with the mineral industry and with universities, can foster the technological innovation seen by the Committee to be so important in the production of raw material and energy goods and commodities from domestic sources.

SUMMARY

The Committee on Mineral Technology has concerned itself with an examination of the status and present role of technology in the mineral industry, an assessment of the constraints to technological innovation in the industry, and an inspection of the forces that are increasingly affecting mineral operations. The Committee notes that although the mineral industry relies on technology to a large degree in converting resources to usable energy and mineral forms it does not base its competitive position on technology but rather on control and access to the best available deposits. These deposits may be large-volume/low-grade bodies or they may be relatively smaller but high-grade concentrations of mineral materials.

Most of the technology used by the mineral industry is generated outside the industry, primarily by equipment manufacturers and other suppliers. What research and development (R&D) is done by the industry is largely oriented to short-term objectives involving existing production operations. Most of a mining company's new development funds are spent in exploring for new mineral deposits which will assure a continuing company operation. This is consistent with the basic operating philosophy of the industry that the possession of a superior mineral deposit is the most secure business position for a company.

An examination of the status of technology in the mineral industry suggests that current mining technology is adequate for the near- to mid-term future[1] and that there is some available technology not now being used. Soft-rock and coal mining technology seems adequate for satisfying many of our near-term mineral and fuel needs but does not appear capable of meeting many of the problems anticipated for the mid- to long-term future when lower grades of ore are likely to be mined, deeper or thinner coal beds worked and environmental constraints are more severe.

Open-pit hard-rock mining technology needs improving, however, because it is rapidly reaching its maximum efficiency due to energy constraints and the necessity of moving large tonnages of rock and ore for long distances.

Underground hard-rock mining will require new technology in excavative recovery of ores and in-situ leaching of mineral materials.

Metallurgical technology, though generally adequate for the near term, is not adequate for the mid- to long-term future. Technological advancements seem especially needed in the treatment of low-grade ores. The problems of fine grinding invite particular attention because of the substantial energy requirements for comminution of ore materials. In addition, the processing of slimes resulting from fine-grinding operations poses a special challenge for improved processing technology to prevent the loss of valuable minerals in the ultrafine fraction of material being treated. Technology for treating finely dispersed minerals, though not yet well advanced, holds great promise in the recovery of many mineral materials. There is likewise much promise in new knowledge of the chemistry of in-situ leach mining and heap and dump leaching as well as the physical characteristics and flow properties of fragmented bodies. Additional targets for improved technology include pyrometallurgical and hydrometallurgical processes in the extractive recovery of metals. Particular attention needs to be given to the recovery of trace elements which may be a beneficial byproduct of ore processing or a contaminant to the environment if allowed to escape during processing.

Despite the need for new technology in mining and mineral processing the Committee finds there are numerous barriers to technological innovation in the mineral industry. The special nature of the mineral commodity market--the establishment of commodity prices by the international market, the imperfectness of short-term supply and demand forces and the inability to fully adjust to supply and demand forces--is a constraint to technological innovation in the mineral industry. Likewise the large capital investments required in the mineral industry have acted as a major deterrent to technological innovation. Large investments in existing productive capacity deter new developments, and the high cost and risk of proving new technology on a scale large enough to be meaningful also discourages new developments. At the same time the organizational structure, management philosophy and professional manpower component of many companies in the mineral industry are geared to a conservative operational approach and this is believed to be a serious constraint to technological innovation. Legislation which once promoted mineral development now is becoming more restrictive in tone rather than supportive, and this has not been conducive to investment in new technology or encouragement of bright young people to enter the industry. Uncertainties in current government policies, laws, and regulations are also serious constraints to technological innovation in the mineral industry. The fact that the mineral industry has traditionally relied on well-proven and relatively uniform technology in its operations--with much of this technology coming from outside the industry--has tended to deemphasize the role of technology in gaining a competitive advantage within the industry. Thus, the industry view of technology has itself constituted a barrier to technological innovation. Finally, the shortage of well-educated and well-trained personnel in mineral extraction and processing is a constraint to development of improved technology.

Despite the many constraints to technological innovation in the mineral industry the pressures and forces for change now being exerted on the industry can be expected to stimulate technological improvements and innovations in the mining and processing of mineral materials. Because of political uncertainties in many foreign areas the mineral industry probably will be forced to give more attention to the development of domestic deposits. The mining of these deposits under increasingly stringent environmental regulations will require the development of improved technology if mining operations are to remain viable. And although capital requirements and existing investments amounting to hundreds of millions of dollars are common to many mineral development operations and are currently a barrier to technological innovation, the expectation of even greater capital needs in the future, as well as increased labor and energy operating costs, may well be a major force on the mineral industry to seek new technology in the mining and processing of ores and mineral fuels.

In response to the movement away from traditional work attitudes and in response to the quest for an improved quality of life on the part of labor, the mineral industry will be challenged to upgrade the laborer's working conditions and general standard of living. For many mineral industry activities this will require new technologies to accommodate the work force available rather than pressuring the workers into the rigidities of existing technology.

The pressures caused by limitations in achieving efficiencies by increasing the scale of operations are an important force to be considered by the mineral industry. The diminishing returns from increased scale of operations suggest that incentives for technological innovation are already present which will lead to a "technological" dependence rather than a "scale" dependence for many mining and processing activities. New technology would seem to offer substantial opportunity for reducing the magnitude of capital investments in mineral developments and for reducing unit output costs.

Although today's technology, on balance, seems adequate for meeting most of the nation's near-term mineral needs the Committee believes that the rate of technological advancement and perception of applicable innovation from outside the industry are not consistent with the demands which are expected to be imposed upon the mineral industry in supplying many mid- to long-term mineral needs. After reviewing the status of mineral technology, barriers to technological innovation, and the forces for change in the mineral industry it is the Committee's consensus that not only is new technology needed but there should be a special federal government effort to seek ways of encouraging technological innovation in the domestic mineral industry. Particularly needed is a federal policy and the establishment of federal programs with incentives for enhancing the technological capability of the domestic mineral industry.

NOTE

1 For purposes of this report the expressions "near term", "mid term" and "long term" are used to mean generally the next 5 years, 5 to 15 years and beyond 15 years, respectively.

INTRODUCTION

The high standard of living enjoyed by most of our citizens has come about as a product of our highly industrialized mineral-based economy, an economy developed on readily available and abundant mineral resource supplies which have provided both fuel and raw materials. For many decades it was taken for granted that these mineral commodities would continue in adequate supply either from domestic or foreign sources and that together with new technologies our standard of living would endure and indeed improve. Unfortunately, it is now becoming increasingly apparent that there are serious challenges, if not limits, to the adequate, dependable, economic and timely flow of certain mineral raw materials to U.S. industry. While in the past the American mineral industry has been able to accommodate to changing conditions and continue to provide the country with its energy and raw material needs, there is now a fear that the rapid rate of change may exceed the capacity of the industry to respond to these newly imposed conditions. Several factors, in addition to the depletion of some of our domestic mineral deposits, reinforce this fear. These include:

1. A greatly intensified concern for the protection of the environment which has resulted in legislative and other actions that have restrained mineral production and have made questionable the viability of new domestic mineral production operations until industry can guarantee the environment will be preserved, reclaimed, or only minimally disturbed.

2. The imposition of the politically-inspired embargo on the shipment of petroleum to the United States from the Middle East with the simultaneous drastic price increase by the OPEC nations--a cartel action which has already been extended to certain mineral supplies. For example, we have experienced a six-fold increase in the price of bauxite, a major source of aluminum, as a result of pressures exerted by an OPEC-like consortium of the countries which traditionally supply the United States.

3. Nationalization of many American-owned mining operations in lesser developed countries of the world and consequent exacerbation of mineral supply problems.

4. Increasing difficulties in gaining access and tenure on the public lands of the United States for mineral extraction purposes.

5. Continuing increase in the demand for raw materials and energy required by the United States to maintain a sound economy and high standard of living.

6. Lack of progress in the United States in developing the technology required to bring marginal domestic resources into production.

7. Increasing capital investment requirement for all new mineral extraction projects and for the expansion of existing operations.

8. A realization, largely as a consequence of the "energy crisis," that restrictions on the availability of energy resources could have a severe influence on the availability of all other raw materials.

It is generally agreed that we will have to rely on foreign sources to supply certain of our major raw material needs (manganese, chromium and tin, for example). Many also feel that it is probably in our long-term interest to minimize, insofar as possible, our dependence on foreign mineral supplies. Recent actions involving nationalization and expropriation of foreign-owned mineral operations on the part of the mineral-rich lesser developed countries indicate that we can expect foreign governments to exert more and more control over the production and export of mineral commodities from those countries. Even Canada and Australia, two highly developed nations which have traditionally been major suppliers of mineral commodities to the United States, have recently increased the restrictions on the development and export of their own domestic mineral resources. Thus it seems essential that the United States give more attention to its domestic resources and to the technology needed to exploit them.

No industrialized country has been so endowed by Nature as to be totally self-sufficient in meeting its mineral resource needs, and the United States is no exception. It is therefore imperative that we continue to develop international policies in mineral affairs that are mutually favorable to the countries concerned. But, for reasons cited above, it is equally important that we intensify our domestic effort to alleviate mineral shortages and the threat of shortages. However, new or improved technology will be required, and the means to implement new technology in a timely manner must be established if significant improvement in our domestic mineral position is to be achieved. Indeed, because of inflation, taxation, government regulations, and delays caused by adherence to regulations, it would almost appear that mineral reserves are being reconverted to uneconomic resources faster than new reserves are being created by new exploration finds or by improvements in extraction technology. These problems were clearly recognized in the Mining and Minerals Policy Act of 1970 which reaffirmed the policy of the federal government to foster and encourage private enterprise in meeting the nation's needs in minerals and mineral fuels. Article 3 of the Act specifically states that it is the continuing policy of the federal government to foster and encourage the research necessary to help assure that these needs are met. Similarly, the National Commission on Materials Policy, operating under the Resource Recovery Act of 1970, recommended in 1973 that agencies with responsibilities in the materials and resources fields undertake appropriate research and development to generate new knowledge and technology, and that they also intensify their efforts to capitalize on available knowledge in the development of our raw materials supply. In each of these acts of Congress and in reports made under these acts there has been repeated reference to the need for the United States to develop its technology as an aid in the discovery, extraction, and utilization of our nation's mineral resources with minimum environmental disturbance.

The United States, thus far, has sustained the upward trend of its standard of living in the face of lower cost foreign labor by a combination of improved technology of its products and its services, by a superior way of organizing to produce those products and services and by a continuing effort to upgrade the educational level of its entire population. While we in the United States are proficient in technological innovation it appears that these proficiencies have not been adequately brought to bear on our domestic mineral supply problems. Clearly, advanced technology is a major vehicle for improving our domestic mineral position, but the rate of technology development and utilization must be increased if this is to happen. Unfortunately, at present we seem to be ill prepared to muster our manpower, knowledge, and skills to this end.

In the federal government sector, in spite of repeated warnings of various select groups ranging from the President's Materials Policy Commission in 1952 to the

National Commission on Materials Policy in 1973 that additional research and development work was needed on the development of a domestic resource base, the nation's science and technology emphasis has been largely in other areas in recent years (space science, defense). A 1969 NRC report even went so far as to say that "...the state of mineral technology in the United States is wretched" (NRC 1969). Yet, in spite of all of these warnings, as the Committee on Materials (COMAT) of the Federal Council for Science and Technology reported in its April, 1976 report, the federal government had allocated only five percent of its total R&D budget to materials research in general and only 0.5 percent of its budget to material supply research in particular (FCST 1976). Except in the time of war-induced shortages, the incentives to develop new technologies in searching for new deposits or in converting low-grade deposits to commercially useable form have been lacking in the face of plentiful high-grade and/or low cost deposits, even though many of these were in foreign countries.

In the university sector, research in the areas of mining, mineral processing, extractive metallurgy, and mineral exploration are practically nonexistent due to lack of funds, manpower, and industry and government programs to provide guidance and direction. This lack of research opportunity has led to a severe shortage of adequately trained faculty members in these fields. Most of those now in faculty positions were educated before and during World War II and will be retiring during the next fifteen years. Many positions have remained unfilled for several years. Clearly, we are in the process of cutting off our most valuable resource--well-trained manpower--at a time when it is needed the most.

In the industrial sector, research and development budgets as a percentage of sales have traditionally been lower in the mineral industry than most other segments of American industry. Though labor-intensive industries have been able to meet foreign competition by the use of advanced technology it remains a fact that capital-intensive industries, such as the mineral industry, have not required technology to the extent of the labor-intensive industries to remain competitive. The mineral industry has largely relied on the economics of scale in order to remain competitive rather than on new technology. Further, insofar as mineral commodities are concerned, the company (or country) with the richest and most extensive ore deposits has always had a basic advantage in the mineral commodity market. Given a choice, a mining company will naturally opt for the investment of its risk capital in high grade/low-cost ore deposits rather than in the development of processes for application to lower grade ore deposits--a perfectly logical and acceptable decision in any high risk, competitive business.

The 1973 petroleum embargo and price escalation, with its consequential effect on all mineral-derived raw materials, has now changed the material and historical perspective of raw material as well as the worth of raw material as contrasted to the worth of technology. Therefore, from a balance-of-trade and national policy point of view, it is reasonable to consider that technology offers an opportunity to use more of our domestic mineral resources both to offset the imbalance in trade in mineral commodities which has burdened the nation since 1973 and also to help to provide an insurance policy against future raw material shortages which might be brought about by forces outside of the control of our country.

In preparing for the Committee activities, it was acknowledged that there have been arguments advanced against the use of a so-called "technological fix" as a means to guard against material shortages. Advocates of this position argue that while history has supported faith in technology the present does not. It has been ably pointed out that since World War II we have exported our manufacturing technology to the extent that the population of the world now is competing for many of the same resources that we have traditionally depended upon and, with lower cost labor and politically-induced incentives in certain foreign countries, these countries now have an advantage over us in the world market place. Thus, so the argument goes, technology is not a valid solution to our material supply problems.

Certain institutional disincentives to technological advance were believed to have undermined our technology position in past years. Dr. William A. Vogely, of the Pennsylvania State University, for example, has noted four institutional disincentives which have hindered technological development in the mineral industry (Vogely 1972). First, when exploration was open in most areas of the world and when the costs of foreign exploration were below the technology cost required to increase domestic exploration, capital was devoted to exploration rather than research. Second, given the demand inelasticity for minerals, pressures for technological developments to decrease mineral costs have been insufficient. Third, technological developments in the mineral industry, while patentable, generally have not been protected due to difficulties in enforcement of international patent law. Fourth, the mineral industry is highly fragmented and the return for innovation generally has been regarded as being poor. Business Week magazine sometime ago addressed itself to the question of disincentives for technological innovation in the mineral industry (Business Week, June 30, 1973:56-63), saying, the "skyrocketing" cost of finding new ore deposits, the steep rise in energy prices and the requirements levied on the industry by the antipollution laws have all taken their toll of the incentive to do more than just keep up with existing production operations.

In an article on technological innovation in industry in general, Business Week pointed to a general slowdown in American innovation as a whole (Business Week, Feb. 16, 1976:56-68). The reason for this was generally summed up by one research scientist quoted in the article as being caused by "...a super-cautious, no-risk management less willing to gamble on anything short of a sure thing." Others cited in the article pointed out that energies, which under prior business circumstances would have been devoted to innovation, are now being devoted just to staying abreast of the times. Increased concerns for product liability, increased production costs, increased consumerism, etc., are all cited as factors which have caused American industry to take a more conservative attitude toward the development and implementation of new ideas, processes, and products. In addition to a general slowdown in American technological innovation today, history has shown that, for a variety of reasons, large corporations , with some exceptions, tend to be anti-innovative (U.S. Department of Commerce 1967). Major innovations in an industry usually come from outside that industry and not by internally generated change. For example, the diesel locomotive was not invented by the locomotive industry, the Xerox copier was not invented by the printing industry, and the Land polaroid camera was not invented by the photography industry. Furthermore, the innovating is done by firms which are relatively small compared with the giants in the industry being invaded.

It was with these thoughts in mind that the Committee entered into its deliberations.

DEFINITION OF TERMS

Throughout the report terms such as "research," "development," "technology," and "innovation" will be used. In order to assure that all readers are interpreting these terms in the same manner as the Committee intended the following definitions are offered.

Research

Research is thought of as being either basic or applied. Basic, or fundamental research is the quest for knowledge and need not have an immediate practical objective. Applied research is the search for a solution to an identified problem and therefore has a specific objective beyond the acquisition of new knowledge.

Development

Development is the next stage to the applied research activity and it generally consists of large-scale tests which are made to establish a technical and economic feasibility of a new process or product and to provide the necessary design information for its industrial implementation. The terms research and development are usually interconnected, (i.e., "R&D") particularly in industry, for the good reason that in many cases it is difficult to define where one ends and the other begins.

Technology

The term technology is used by some to describe the entire R&D process but the most apt definition of this work is given in Webster's dictionary: "...the totality of the means employed to provide objects necessary for human sustenance and comfort." A company, therefore, which has a massive R&D effort but operates antiquated and inefficient plants cannot claim to "high-technology"; conversely, a high-technology company may spend little on in-house R&D but have a policy of rapidly adopting in its operation the technical innovations of others.

Innovation

The term innovation is used more and more with regard to industrial technology and will be used extensively in this report. It means simply: the introduction of new things or methods; i.e., innovation represents the total scope of the processes by which ideas are conceived, developed into being and finally implemented. It begins with the creator and ends with the user. Its definition stresses the act of bringing about something new and putting it into use.

Technological Innovation

The term technological innovation necessarily arises from the definition of the two terms of which it is comprised. However, it should be realized that innovation itself is not purely a technological matter. In fact, science and technology are simply tools used in engineering, and engineering is only one facet of successful technological innovation. Economics and the business climate itself are major components of innovation in an industrial sense for, unless market conditions are favorable and the cost of production is favorable a technological innovation cannot be successfully made. Blockages to innovation are referred to as "constraints," "barriers" or "disincentives." Suffice it to say at this point that the development of new technology need not in and of itself lead to technological innovation. Many additional factors which are not science- or technology-related may act to postpone or even to counteract innovation.

Three basic types of technological innovation have been identified (Marquis 1969:30). The first of these might be called <u>"nuts-and-bolts" innovation</u> and is essentially product differentiation--new product forms, a minor change in product formulation, use of a new piece of machinery in a process, etc. The other two categories involve more fundamental innovation. First, is that characterized by a <u>major technological advance</u>--something that will provide opportunity for an entirely new technological process or product. The development of longwall mining of coal might be one such example in the mineral industry. Another example might be the development of the froth flotation process. The second type of fundamental innovation is that involved in the <u>creation of a large new system</u>. There may be no new discoveries or startling inventions made while developing a large system configuration, but the totality of coordinated human enterprise is intellectually challenging in the extreme. While many of the accomplishments of the space program are often cited as illustrative examples of this type of innovation, it is perhaps just as accurate to say that some of the larger mining projects today which require the interactions of large numbers of people in a number of specialty areas ranging from finance to environmental assessment would be classified in this category of technological innovation. A system for utilizing the oil shale reserves of Colorado, which accommodates concurrent problems in retorting technology, financing, environmental protection, etc. might be an illustrative example of this type of innovation within the mineral industry framework of this report. Another example might be a system of recovery of nodules from the sea bed.

CHAPTER 1

THE STATUS OF TECHNOLOGICAL INNOVATION IN THE MINERAL INDUSTRY

THE ROLE OF TECHNOLOGY IN THE MINERAL INDUSTRY

The mineral industry, whether in the United States or in a foreign country, is not generally known as a "high technology" industry despite the fact that its very existence is dependent upon technology. The very definition of an "ore" reflects the need for technology because a mineral deposit can be considered an ore reserve only when and if the technology is available to process it economically into a commercially usable commodity. Thus, technology is the very heart of the mineral industry. The froth flotation process, for example, which was developed in England in 1906, has made such a tremendous impact on the mineral industry that it has been said there would be no industry as we know it today if it were not for the invention of this process (Milliken 1962:1). Certainly the large porphyry copper deposits of Bingham, Utah, and Butte, Montana, as well as dozens of others in the American Southwest and elsewhere in the world would never have been developed to commercial production without the froth flotation process. And yet, this process in all of its simplicity cannot truthfully be termed "high technology" in spite of the huge impact it has had on our society. The mineral industry, in fact, has existed and has existed well in its service to society by the use of relatively basic technology. Comminution processes which can be traced to the very beginnings of civilization and smelting processes which can be traced to the beginnings of man's industrialization form the foundation of the industry.

Unlike the manufacturing industry the mineral industry is not driven by the technological obsolescence of its products, for its products are the basic building blocks of the industrial sector of the economy. Traditionally, the major forces controlling the mineral industry have been the need for the discovery and acquisition of the best possible mineral deposits. Hence, the behavior of the industry has been oriented toward the development of a mineral-exploration capability rather than toward the development of a process-technology capability (Simmonds 1976:5-15). As a consequence, technological efforts of this industry are largely aimed at the development of the capability necessary to locate mineral deposits. In comparison with the chemical industry or the manufacturing industry there is little truly proprietary technology in the mineral industry. Mineral technology is generally an open matter available at little or no cost to all who are interested or is obtainable from suppliers to the industry.

PRIOR STUDIES OF THE STATUS OF TECHNOLOGY IN THE MINERAL INDUSTRY

Two studies have recently been conducted of R&D and technological innovation in the mineral industry. The first of these was conducted by Battelle Columbus Laboratories for the U.S. Bureau of Mines (Battelle Columbus Lab. 1972). This study inquired into the R&D budgets of a number of major American mining companies and into the corporate philosophy behind the budgets. Seventy-two companies participated in this study. The second study was conducted by the School of Business Administration of the University of Western Ontario on behalf of the Department of Energy, Mines and Resources of Canada (Richardson et al. 1976).

The Battelle study indicated that during the years 1970, 1971, and 1972, the 72 companies surveyed spent 88 percent of the "exploration, research and development" money on exploration and 12 percent on research and development. Further, of the R&D expenditure, fully one-quarter was spent on the development of new exploration techniques. Thus, in effect, over 90 percent of the E, R&D budgets was concerned with exploration. The remainder of the R&D expenditures was divided almost equally among mining technology, processing technology and a miscellaneous category which included pollution control technology, minerals beneficiation technology, recycling technology, and land reclamation technology in diminishing order.

The Battelle investigators cited a number of trends which became apparent as a result of their study:

1. Expenditures for R&D were largely a function of the availability of discretionary money in the company. Thus, when profits were down R&D was down and vice versa.

2. Increases in R&D expenditure during the time period studied seemed to be a function of the R&D work underway; i.e., if certain specific work seemed to

offer the company an opportunity for better profits, then the budget was more stable and less sensitive to the immediate economic condition of the company.

3. Decreases in R&D expenditure seemed to be a function of depressed profits or falling prices that reflected surplus supplies. This was particularly evident for R&D relative to products with shrinking markets such as Frasch sulfur. In such cases, effort was directed only to current production problems.

4. A low level of R&D expenditure in a particular industry tended to reflect the maturity of the industry. For example, low level funding of R&D expenditure in the phosphate industry was interpreted to reflect a mature technology of extraction and utilization and to some extent to the belief that there would be diminishing returns on R&D work performed on traditional problems, such as the slime problem.

5. The type of R&D undertaken and changes in budgeting among the functions (mining, beneficiation, etc.) were largely dependent upon perceived needs of the company. This was quite evident in the area of pollution control where the budget for the pollution control activities increased as federal and state regulations became more stringent. Budget increases tended to be focused on areas into which the company foresaw its immediate needs developing, rather than on the solution of basic problems. Those areas, of course, varied according to the nature of the industry.

In the final analysis, the Battelle group concluded, individual companies adjust their R&D budgets to reflect: (a) the economic well-being of the organization, (b) the status of the organization within its industry, (c) specific problems associated with the extraction and utilization of the minerals with which it works, and (d) outside influences that the organization cannot ignore. For any given year, the initial planning budget will usually mirror the personnel already available with adjustments for anticipated changes derived from the four factors mentioned above. However, from year to year, the directional trend of R&D expenditures does not necessarily correlate with the viability of the company or its industry due to the time lags between the start of R&D and the use of the results in its operations.

A majority of the respondents to the survey indicated that their company's current R&D emphasis was on the solution of immediate problems and short-term payoffs for their R&D activity. Most respondents were concerned with increasing the utility of their research, by choosing problems of maximum impact to the company and problems which have a high probability of being solved in the short term. Lastly, numerous respondents referred to the role of equipment suppliers in providing new technology to the industry through the introduction of new and improved equipment pointing out that by means of R&D activities of the manufacturing industry, the mineral industry receives new technology resulting in improved operations, increased cost savings and profitability. In this respect, the equipment supplier provides both a product and a service to the mineral industry.

While admittedly limited in scope, the Battelle study seems to describe adequately the present status of R&D in the domestic mineral industry. The picture presented depicts the mineral industry as an industry which relies on its R&D activities principally in the support of its existing businesses and largely as a defensive measure as individual companies protect their stature in the industry. Exploration, not R&D, has been the principal tool used by companies in the mineral industry in order to advance their position. Obviously, mining companies have viewed the acquisition of the best mineral deposit as their main competitive advantage rather than the development of the best technology. Thus, it has been exploration rather than R&D which has fulfilled the requirements of corporate long-range growth in the areas of the general company interest and in areas for diversification.

The Canadian study, while far more intensive and more structured than the Battelle study, was largely supportive of the Battelle findings in spite of the continual reference to the fact that conditions in the Canadian industry were the result of conditions which were unique to Canada; i.e., a large percentage of foreign (U.S.) ownership and an absence of mining company and mining equipment company R&D facilities in Canada itself. The Canadian study reported as follows:

1. In both small mining companies and those with limited ore reserves, the perceived critical task for the company will be the discovery of new sources of ore. Except in certain "one shot" companies this behavior pattern dominated this category of mining company and these firms spent little or nothing on process innovation.

2. Having accepted risk in the exploration activity necessary in discovering a new ore body, the management of mining companies will minimize risk in the process equipment used in the mine. This will act to inhibit process innovation. Innovation within a mining company develops through necessity rather than through a general search effort for new techniques.

3. Mining companies will only be innovative in process technology when the risk perceived by management in the development of the new technology is justified by a threat to the survival of the firm. Two groups were identified, one group for which innovation represents a source of competitive advantage and possibly economic profit, and one for which innovation is a response to adverse business conditions. Large firms engage in technological development on a major scale; small, non-integrated firms rely on process equipment suppliers for their innovations. Actually, four distinct strategies were identified as being utilized by Canadian mining companies with regard to R&D as a function of the size of the company:

    a. a passive strategy utilized by the large majority of small- and medium-sized firms; i.e., consultants and equipment manufacturers relied upon for new technology,

    b. a defense strategy utilized by growth oriented medium-sized firms; i.e., firm has a research department but consultants and equipment manufacturers are still used for new technology,

    c. an active strategy employed by the smallest five of the eight largest companies; i.e., firm has a research department and an engineering-design group for technological innovation, and

    d. an integrated strategy employed by the three or possibly four largest companies; i.e., firm performs its own R&D, engineering and construction work.

4. The majority of process innovations in the mineral industry are conceptualized in the mining company itself and specifications can be determined for the process innovations within the firm. For the most part, however, equipment suppliers are relied upon for equipment design and manufacture.

5. A major, formal continuing commitment to R&D is required for commercially successful innovation to take place. Long lead times for R&D and longer times yet to bring a new process into production are the characteristics of the industry. Thus, for the R&D effort to be productive a commitment of time and money is necessary with the patience to see a project through to fruition--a process which may require as much as ten years or more.

From the studies cited, it appears that although the mineral industry relies heavily on technology for the conduct of its business, companies in the industry have not generally based their competitive position in the industry on proprietary technology. The competitive position of these companies has been largely based on their possession of a unique ore deposit which, by virtue of its grade, mineralogical composition, size, location, etc., affords the individual company protection and security in the conduct of its business. For this reason, process technology which is undertaken by a mining company is undertaken for the purpose of preserving its capability to exploit the ore deposit or deposits on which its business is based.

- *It is the opinion of the Committee that, while the philosophy of the mineral industry regarding technology has served the mineral industry well in the past when better ore deposits were available for acquisition, it will not provide the technology, nor even the incentive to develop the technology, necessary to operate in a mode wherein ore deposits of lesser grade and uniqueness are the only domestic mineral sources available to the industry. Further, while "technology fixes" have more-or-less successfully accommodated many of the environmental, health, and safety restrictions recently placed upon the industry, the cost of such interim solutions has been excessive and will not be the long-term solution to conditions imposed upon the industry by society.*

THE STATUS OF TECHNOLOGY AND PRESENT TECHNOLOGICAL NEEDS OF THE MINERAL INDUSTRY

The Committee, through the research of its individual members and workshop participants, attempted to determine the present status of technological innovation in the mineral industry and to define briefly some of the specific future technological needs of the industry. The following discussion describes the Committee's separate findings and conclusions for the mining sector of the industry and for the metallurgy sector of the industry.

Mining Technology

Mining, in its broadest historical sense, is the winning from the earth and sea any of the mineral material, solid, liquid, or even gaseous, for the benefit of man. While the term "mining" is generally understood as referring only to the extraction of solid materials, more modern terminology, such as "solution mining," refers to the removal of materials from the ground by the process of leaching in-place by a solvent. This solvent is generally water, as in the case of salt or potash production. An allied process is the Frasch process for sulfur recovery whereby hot steam is used to melt the solid sulfur in-place and to transport it to the surface where it can solidify by cooling. "In situ leach mining" refers to the use of a chemical solution, such as sulfuric acid, for the leaching of a metallic constituent, such as copper, from an ore body. Moving further afield, the in situ combustion of coal might be considered a mining process too. While some of these unconventional methods will be discussed in this report, in general the word "mining" will be used in the conventional sense of either hard rock or soft rock mining in which miners are directly involved.

Status of Mining Technology

To many people the word mining itself connotes the use of archaic technology, reminiscent of pick and shovel days, in the movement of earthen materials; in actuality, continuing advances have been made in mining technology over past years. For example, a few technological innovations made in the last 30 to 50 years in the United States as well as abroad are:

a. improved ventilation, visibility and working conditions for the health, safety and comfort of the miner,

b. improved drilling equipment, the machine, the rod and the bit as a combination,

c. trackless mining equipment, first developed to mechanize ore loading and ore transportation operations, now expanded to the drilling function, to aerial platforms for loading explosives, for scaling, rock bolting, installing pipes, lighting, etc.,

d. improved blasting agents and blasting practices making the operation safer and more efficient,

e. improved mine development practices and equipment, e.g., mechanization of shaft sinking, raising and drifting practices. (Boreholing has added a new dimension to mine design.)

f. larger and more efficient units of hoisting equipment, fans, compressors, pumps, etc.,

g. application of rock mechanics principles in both underground and open-pit mine design.

h. open-it mining technology and the economic recovery of large, low-grade mineral deposits,

i. continuous-mining equipment for coal and soft-rock mining, and

j. self-advancing longwall supports and shields.

These developments have largely been international in origin and have been evolutionary--one step leading to another as dictated by necessity. Unfortunately, in the absence of spectacular technological "breakthroughs" the mineral industry is often condemned as lacking in technological innovation.

An important question is: Is the present status of mining technology sufficient to meet today's and tomorrow's needs? Arguments can be made that mining technology has been sufficient, at least up to the present time, and that except for national emergencies and the brief economic disruption in the 1973-1974 period, Americans have never been without the energy and raw materials necessary to fuel and to build their society. Actually, in constant dollars, many mineral commodities are as cheap or cheaper than they were twenty-five years ago. However, the foremost question must pertain to whether or not mining technology is adequate for tomorrow's needs. To this question we must conclude that it is not obvious that the present technology can adequately respond to the needs foreseen for the future.

- *The Committee believes that current technology is adequate from the point of view of what can be practically implemented in the near- to mid-term future. All that is available probably is not now being used and there is not going to be anything new available in time to influence the near- to mid-term future. The Committee concludes, however,* *that presently available technology does not provide the capability for meeting the problems anticipated for the mid- to long-term future when ore grades are likely to be lower, and environmental constraints have been made more severe.*

Mining technology seems to be advancing at least at the rate it can be assimilated into practice at the present time, and, perhaps the rate of advance of technology is a better measure of accomplishment than the status of technology. Some have pointed to an insufficiency of trained personnel to improve existing operations; others have pointed to the necessity of expending available capital on non-productive investment for sociological purposes--air-pollution-abatement equipment, safety devices, etc.--rather than on new installation of productive equipment. Regardless of the reason, the history of the industry seems to indicate an evolutionary technology which is fostered by need when need is encountered; when extreme difficulties are encountered, technological innovation can and does occur.

As both the Battelle study and the Canadian study indicated, much of the technological innovation of mining is brought to the industry by the equipment manufacturers who innovate in order to maintain a competitive position in their industry. When the mineral industry is in a boom condition, however, equipment innovation does not take place because manufacturers have no need to innovate when they are at full production and can sell their entire output. Unfortunately, when the mineral industry is at a low ebb, equipment manufacturers are restrained from new development because business is poor and new product development is costly and risky. New equipment opportunities do arise, however, when a field starts to change rapidly. The movement of coal mining to mechanization after World War II, for example, led to new opportunities for equipment manufacturers. The hard-rock mining industry shows evidence of approaching the same transition as the coal mining industry has undergone already. The mining equipment manufacturer also provides a common denominator for the mineral industry. Equipment sales are now made to world-wide markets. Any one country's market, in a field like underground hard-rock mining technology, is generally not large enough to justify the investment required and the time that has to be spent to develop or to improve a new product. This fact is manifested by the presence of European mining equipment sales offices in the United States and the sales offices of American companies in Europe, South Africa, Australia and Canada. The very presence of an international mining equipment supply industry is itself a form of technological transfer within the mineral industry.

Requirements for New Technology

While the Committee concluded that the present status of technology in mining was adequate for the present (in view of the limitations of assimilating that technology into production operations) it also defined general areas where the Nation was lacking for the fulfillment of future needs. These are areas of technology which must be reinforced if the environmental and the raw material and energy supply goals of the Nation are to be met in the mid- to long-term future. These technological requirements are necessarily different for the several types of mining in use today and for those foreseen for the future.

Coal Mining

Soft-rock and coal mining technology has generally been advancing at an adequate rate. Further, because of the U.S. Bureau of Mines research, development, and demonstration programs in coal mining, continued advances in this field are expected. Approximately 35 percent of the Bureau's coal mining research program is directed toward improving the health and safety conditions in the mining of coal, and 65 percent for advancing coal mining technology which will direcly lead to advances in coal mining methods and equipment.

In spite of these federal research programs, productivity in coal mining continues to be a problem. At 8.5 tons per man shift for underground mining in 1976 compared with 15.9 tons per man shift in 1968-69, there is a great deal of room for improvement. Productivity, which was lost partially due to unstable labor conditions, the lack of dedication in the new labor force and partially due to the regulations placed on underground coal mining by the Coal Mine Health and Safety Act of 1969, can be made up, or at least the trend reversed, by improved mining practice and equipment. While productivity in surface mining is higher, 25.5 tons per man shift in 1976, increased environmental regulations already threaten this level of productivity. Another problem is that of recovery. Deep mining recovers an average of 55 percent of the reserve and surface mining approximately 90 percent. At a time when the nation is resource-conservation conscious, recovery must be an important concern. However, the Committee cautions that in view of energy constraints and economic constraints ultimate recovery should not be the governing goal of new technology; rather, a balance must be struck between energy and dollar expenditure and resource recovery.

Surface Coal Mining. A common and most important problem for any system of surface mining (strip, open pit, terrace mining) is land and environmental restoration.

- *The Committee recognizes the need for the definition and development of technology for an improved, selective, and inexpensive land reclamation procedure which will exclude or minimize any losses of agriculture-quality top soils, where available, and which will reestablish a balanced environmental condition to lands disturbed by surface mining.*

  Research and development effort should be oriented to: (a) the definition of an efficient method or system for top soil removal and redeposition and (b) the development of high capacity equipment for mechanized operation of land reclamation or even environmental enhancement.

Underground Coal Mining. Underground mining of coal is concerned with three major kinds of operations, namely, (a) mining of thick coal seams, (b) mining of multiple coal seams, and (c) mining of steeply dipping coal seams. These operations, at least in part, involve different mining procedures but all of them are manifested by low productivity and inefficient resource recovery. The U.S. Bureau of Mines has conducted programs in many of these areas in recent years.

- *The Committee recognizes the importance of research and development in the following areas:*

  a. *improved resource recovery,*

  b. *improved mining methods--including hydraulic mining,*

  c. *improved mining equipment providing higher efficiency and better working conditions,*

  d. *improved ventilation and other methods of gas and dust control,*

  e. *improved subsidence control and surface reclamation procedures, and*

  f. *improved coal cleaning methods for recovering high-grade coal from bulk mined thin seams or high slate content coal.*

Underground Coal Gasification. For those coal seams which are inaccessible or uneconomic to mine by conventional mining techniques, in situ coal gasification offers an alternative method of resource recovery.

- *The Committee endorses the development of technology for the in situ combustion and gasification of low quality coal seams and/or multiple thin seams and/or deposits which are located too deep below the surface and which are too difficult and expensive to recover by conventional mining methods.*

Hard-Rock Mining

Although hard-rock mining in the United States has not received the level of federal funding that coal mining has enjoyed in recent years, the United States leads the remainder of the world in some aspects of hard-rock mining. Regardless, the Committee has identified areas needing attention if future needs are to be met.

Open-Pit Hard-Rock Mining. Open-pit mining technology has been advancing satisfactority, and the United States is undoubtedly the leading country in this field. However, this technology is rapidly reaching its maximum in efficiency due to energy constraints and to the necessity of moving large tonnages of rock and ore long distances. The future of very deep open-pit mines is already in jeopardy for these reasons and for environmental reasons.

- *The Committee believes that research programs should be initiated for the purpose of developing methods for:*

    a. more efficient material handling in open pit mines, and

    b. the solution of land reclamation problems when material cannot be returned to the excavation; i.e., creating an environmentally acceptable condition by the creation of new land forms and by landscaping.

Underground Hard-Rock Mining. The variety of ore deposits, characterized by different geological and hydrological conditions, structural features, location, altitude, shape, size, kind, value, physical and mechanical properties of the ore body, is so extensive that it is impossible to define a simple and perfectly valid classification system for problem analysis. The Committee considered two general categories of underground mining on the basis of the fundamental technological principles of mining, namely, excavative recovery and in situ recovery.

Excavative recovery represents the mining technology by which nearly all ore is mined today. Practically all existing underground ore mining systems would be classed as excavative recovery technology. In this method the ore is removed from the deposit by bulk mining methods. Two categories were considered: ore deposits which are large in three dimensions and ore deposits which are small in one dimension. Mining technology for ore deposits which are large in three dimensions (salt, potash, porphyry copper, etc.) using mass-mining methods and/or large trackless equipment is advancing satisfactorily. Representative of these methods are the large-dimension stoping methods, with or without backfilling, and caving methods. The most efficient mass-mining method of large ore deposits is block caving or a modification of block caving. Mining technology for ore deposits which are small in one dimension is less well developed. Here, either meticulous and selective mining must be practiced or large quantities of unwanted waste material must be mined with the ore.

- *The Committee feels that research programs should be undertaken to improve hard-rock underground mining technology by:*

  a. *developing a better understanding of the gravity flow of caved rock masses for minimizing dilution and ore loss and for a better stability of openings through which loose rock must flow,*

  b. *developing continuous-mining systems for medium hard and hard-rock ore bodies,*

  c. *developing continuous, high speed mine development machines,*

  d. *developing low cost methods of stabilizing fill material, and*

  e. *developing backfilling methods to enhance ore recovery and for the proper disposal of waste rock and tailings.*

In situ leaching represents a newer concept in metal mining in spite of the fact that several non-metallic minerals, namely, sulfur, potash, and salt, have been traditionally mined by related solution mining methods. In the in situ leaching of copper and uranium the metal values in the ore are leached from the ore minerals while they are still in place in the ground through the use of various solutions pumped into the ore deposit. Metal bearing solutions recovered from the ore deposit are then treated on the surface by hydrometallurgical techniques to recover the values as a metal or as a metal-containing chemical for further processing to a metal. Another method, borehole mining by high pressure and high volume jets cutting cavities at the bottom of bore holes and pumping the resulting slurries to the surface for treatment, also represents a newer concept in mining. Such mining methods offer the opportunity to recover valuable materials from shallow, marginally and submarginally economic ore bodies in the immediate future and possibly from very deep ore bodies in the more distant future without major disruption of the surface.

- *The Committee sees a strong need for research that will lead to the practical development of mining methods having a minimum disturbance to the surface. Such research should range from the development of practical hydrometallurgical systems for the dissolution and recovery of ore values in place to the development of methods of increasing permeability through better fracturing methods or rubblizing rock in place. Attention should be paid to the prediction and assessment of fluid flow characteristics in fractured rock masses and to the flow properties of slurries.*

Additional Considerations

Regardless of the mineral commodity to be mined or the type of mining method to be used, the Committee recognized that certain generalities must be considered for improvement through technological development. For example, during the pre-mining stages of a mineral development project it would be valuable to have improved information regarding the nature of the ore body and the rock masses to be penetrated during mine development and mining itself. Such information would assist in the decision-making process by which the project is justified, would improve the accuracy of cost estimations for the project, would provide for the early provision of safety measures in the mine design for the protection of the miners and would improve the efficiency of capital utilization in the mine design and implementation.

- *In the judgement of the Committee, research and development programs should be established for the development of engineering methods for the determination of rock properties in situ and for the general improvement of mine design technology.*

Metallurgical Technology

The terms metallurgy and metallurgical technology employed by the Committee include operations involved in the separation of valuable mineral constituents from the undesirable or waste constituents in an ore, followed by the processing of valuable mineral constituents to obtain a commercially useful metal product. Thus, the two principal areas of interest are mineral processing and metal extraction. The definition employed here also includes those operations in the primary production of metals in which scrap is obtained from the production of useful objects from metals (industrial scrap), and in which scrap is reclaimed from obsolete and discarded machinery, structures, ships, and other waste products (obsolete scrap).

Solution mining has been employed essentially as a mining operation for mineral salts and sulfur as was noted in the section on Mining Technology in this report. When the general concept is applied to metals, uranium and copper being examples of current interest, the process of in situ leach mining is considered to become a blend of mining and metallurgical operations. This is because the chemical aspects of in situ leach mining of metal minerals are very closely related to those of heap and dump leaching, an area which traditionally has been the responsibility of mineral engineers and metallurgists. As a consequence, these aspects of in situ leach mining are considered as a metallurgical process for the purposes of this section of the report.

Included also in the coverage of this section is the processing of coals to remove undesirable constituents, such as sulfur and ash-forming minerals, by physical means. Such processing is expected to be of great importance in the decades ahead as the pressures rise for increased utilization of coal. It is to be recognized that many of the methods that have been employed traditionally for the cleaning of coals are typically mineral processing methods utilized in metal-mineral extraction.

Status of Metallurgical Technology

The important innovations in mineral processing and metal extraction in recent years have come from a number of countries, including the United States. For example, American industry has played a dominant role in the development of processes for the direct reduction of iron ores, and the AOD (Argon-Oxygen Decarburization) process for refining of stainless steel is an American development. The United States has also been a strong participant in the development of hydrometallurgical processes for nonferrous metal extraction. A general listing of innovations would show that in recent years many have come from other countries such as Finland, Japan, Canada, Mexico, Sweden, Austria, England, etc. As is the case with mining technology, the development of innovative engineering systems is international in character, and the know-how necessary to install a new process apparently can be obtained for a cost that is very modest in comparison to the capital cost of the new plant.

A plant producing metals today has a market that is essentially international in character. It has been pointed out, for example, that a pound of copper can be shipped anywhere in the world for about five cents. As a consequence, the price of a metal can be set by the costs of a foreign producing plant which operates under conditions which may differ in important ways from those of the American producer. Two important areas of difference are ore grade and environmental control. The continental United States has been explored extensively, and it appears that with few exceptions the domestic producers of the primary metals will have to depend on low-grade deposits in the future. On the contrary, major producers of some metals in other countries still depend on relatively high-grade deposits. The recent emphasis on protecting the environment in the United States has resulted in large increases in the capital and operating costs of a plant because of requirements to avoid damage to air, water, and land quality. The increase in capital costs ranges from 10 to 40 percent for a metallurgical plant, but will vary widely depending on the type of plant and its location. It is recognized that appropriate care of the environment is essential in the operation of an industrial plant today and major strides have already been made in this regard in the United States. However, in some countries that are important sources of the world's supplies of metals, plants can operate unimpeded by concern for the environment. Thus, in a market where prices are determined by international competition an American producer can be confronted with a serious economic challenge because of the costs of mining low-grade ores and the additional costs associated with protection of the environment. There are, of course, other considerations in this competition, but they are outside the scope of this report. The net result is that the producing domestic industries face a pressing need for new and improved technologies that simultaneously enable them to meet the problems of processing low-grade ores and protecting the environment.

The associated high costs of utilizing new technology act to inhibit the flexibility of the industry in adopting new methods. This matter is now of great importance to the copper industry in particular. Although a number of new pyrometallurgical processes for smelting sulfide concentrates have been developed in recent years, economic factors limit severely the ability of the industry to use the new technology.

- *It is the consensus of the Committee that, while current metallurgical technology may be adequate for the near term, much of it may not be adequate for the mid- to long-term future. In the face of anticipated future trends in ores available for treatment, today's technology could be totally inadequate. This is especially serious considering that present technology is already too expensive in capital and in energy requirements to make new operations feasible in many of the primary metal commodities.*

Requirements for New Technology

As will be pointed out later, with the presently available technologies for extracting aluminum, copper, and zinc, the costs of producing these metals exceed the present market prices if new production capacity is required. Thus, radical changes in technology are needed if these industries are to be economically competitive in the future. As was noted earlier, the most important issue is that the domestic supplies of many of our metals and minerals will be drawn from lower and lower grade deposits or from more refractory ores. An example of the trend is that the average grade of ore from a major porphyry copper deposit in the United States has dropped from 0.7 percent copper in 1965 to 0.55 percent in 1975. It is predicted that it will be 0.2 percent by 2000. Technological advancements in a number of areas of metallurgical processing are needed for the processing of lower grade ores as discussed briefly below.

Comminution. Only a small fraction (approximately 5 percent) of the total energy of crushing and grinding is actually utilized in the fracturing of the ore. The rest is dissipated in various other ways. This is a serious economic loss when one considers that, on the average, comminution consumes approximately one-half of the energy necessary to mine a low-grade ore and prepare it for subsequent steps of mineral processing. A second problem is that with most ores, fine grinding in preparation for flotation or other separation processes results in a significant fraction of the ore being converted into very fine particles (minus 10 microns in size). Particles in this size range are extremely difficult to handle, and may interfere with processing operations such as screening, flotation, and leaching. Consequently, this fine fraction of the ore may have to be removed as slimes which then must be discarded. In addition to the difficulties in removing these slimes, a significant loss of the valuable minerals in an ore may occur, and their disposal can cause serious environmental problems. The amount of slimes and the necessity for their removal varies with the type of ore being processed. With sulfide-type, porphyry copper ores, they may constitute 10 percent of the ore being processed. While they may be treated by flotation at a slight reduction in the recovery of copper, they do involve problems in the disposal of tailings. A more serious problem is that of slimes encountered in the processing of raw phosphate rock in Florida. Typically, approximately 30 percent of the ore as mined becomes slimes which must be discarded since their presence interferes seriously in subsequent processing of the phosphate rock. In addition to the loss of valuable phosphate minerals, there is also the serious environmental problem in the disposal of these slimes which have a high content of clay. The loss of the valuable constituent of an ore to slimes may be serious if the primary ore mineral carrying that constituent is particularly friable or if it is so intimately interlocked with worthless mineral materials that fine grinding is essential.

- *The Committee feels that, to meet the need for improved methods of comminution, additional fundamental research is needed to better understand:*

    a. *the processes of fracture in polycrystalline, polyphase minerals and ores, and*

    b. *the role of surface forces in dry and wet grinding and the role of reagents which might be added to the process to modify these surface forces.*

- *The Committee also feels that work of a practical nature is needed toward the development of:*

a. *new and improved methods of comminution,*

b. *new and improved methods of separating fine from coarse material during grinding operations, and*

c. *methods for the possible utilization of a crushing or grinding process as a reactor for the purpose of performing the first chemical step in mineral extraction.*

- *The Committee recognizes that there has been considerable emphasis placed on the modeling of grinding units in recent years. Such models are helpful in predicting what efficiencies are theoretically possible but have been of limited value in analyzing the problem itself. The Committee believes that additional work is necessary in developing the feedback systems and methodology from operating comminution processes to determine how closely an industrial circuit is approximating the modeled performance or even how closely the circuit is approaching its design performance.*

Mineral Concentration Processes. A large variety of physical and chemical processes are employed for separating ores by size and by mineral constituents. In the processing of low-grade ores, it is often necessary to crush and grind an ore to very fine sizes to liberate the valuable mineral constituents, or to expose these constituents to leaching solutions. Particles in the size range of less than 20 microns are very difficult to handle and process effectively because of surface forces. As noted above, this is the size range where slimes are formed. Research is needed to develop information on the effect of these forces on the behavior of very fine particles and to develop improved physical and chemical methods for processing such fine particles. It is expected that the development of new and improved methods of classification of ores by size and by flotation techniques would be stimulated by such knowledge.

The traditional methods of ore concentration such as flotation, gravity concentration, and electrostatic and magnetic separation have probably all been stretched to the limits of available technology. Most processes employing these methods were developed in an era when ores were richer and the valuable constituents were less finely disseminated. Improvements in the use of these methods are essential to obtain a better recovery of the desired minerals and to make the mining and processing of low-grade ores economically attractive. The need to develop improved techniques of gravity concentration for the recovery of fine coal and other minerals, and the need for improved methods of magnetic separation for the recovery of weakly magnetic minerals are especially pressing. However, there is a general need for increased effort to extend the capabilities of all types of concentration methods, particularly as they may be applied to the treatment of low-grade ores. An example of a new method of flotation that may find wider use with further development is flocculation-flotation which has been installed at the Tilden Mine in Michigan. Very fine particles of iron ore are caused to floc together by the addition of a reagent to the ore. These flocs are then separated from the particles of gangue by flotation methods. While this process is far from perfect, it represents a new approach to a difficult problem.

- *The Committee attaches a particular importance to fine-particle technology for the processing of low-grade ore. Research is needed on the understanding of particle-to-particle forces in the presence of various ionic aqueous solutions and in various types of organic reagents as used in mineral separation processes.*

The deficiencies in the technology for the physical processing of minerals apply as well to the processing of coal. The anticipated increased use of coal will require greatly improved processing methods for cleaning coals to remove slate, pyrite and other undesirable constituents.

Extractive Processes. The technology for mineral processing and metal extraction has many facets, and the processing methods employed vary widely with the type of mineral or metal being processed, local conditions as to transportation, water supply, the environment and the cost and availability of fuels. Broadly, the choices are between pyrometallurgical and hydrometallurgical processes for the extraction of metals. In each of these areas there is a wide diversity of processes that might be employed. In spite of this diversity, the levels of effort for research and development in the two areas in the United States are very limited. The industrial effort is usually directed to relatively short-term work related to a given ore body, mine or metallurgical plant. Longer range research is being conducted on a very modest scale in the universities, and it is supported principally by the National Science Foundation. The efforts in extractive metallurgy by the federal government are limited to the programs in the Bureau of Mines, which for many years have been directed principally to the processing of domestic low-grade ores. In recent years, the Metallurgy Program has occupied a relatively small portion of the Bureau's budget.

- *The Committee is strongly of the view that the current levels of research and development in extractive metallurgy, in industry, in government, and at universities, is inadequate to meet the longer term needs of the country.*

Pyrometallurgical processing includes the high temperature physical and chemical operations of agglomeration, smelting, refining, and solidification that are employed in the production of metals. Major changes have been made in the field in the past two decades; examples are the invention of the top and bottom blown converters for oxygen steelmaking, the application of the fluidized bed in many places such as in roasting of sulfide ores of nonferrous metals and the reduction of iron ores, and the development of several new methods for processing copper concentrates. Many of these advances have sprung from a technological base that was started in antiquity, and much of the understanding of the behavior of these systems has been developed empirically. On the other hand, a good understanding of the physicochemical behavior of the principal constituents in these systems and reactions among these constituents has resulted from research in academic, industrial, and governmental laboratories in recent years.

In spite of the progress that has been made, the present technological base in pyrometallurgy is inadequate to meet a number of challenges that face the metals-producing industry. The need for greater activity in research and development is very broad, but the major problems to be faced arise because of the need of the industry to adjust to the increasing cost of energy and the limited supplies of good quality fuels, such as coking coals and natural gas, to exact a higher recovery of valuable metals, and to adapt to requirements for protection of the environment. Research effort should be directed to developing a better understanding of conditions that control the transfer of heat and mass in pyrometallurgical processing systems, and new methods are needed for reducing and smelting iron ores with the direct use of bituminous and lower ranked coals as the principal fuels.

- *The Committee concludes that research is needed on the physical and chemical nature of pyrometallurgical processes to support the development of operations:*

a. *that are more economical in the use of energy and scarce fuels,*

b. *that exact a higher recovery of valuable metals, and*

c. *that provide for more convenient and more efficient pollution control.*

<u>Hydrometallurgical processing</u> includes the various processes whereby aqueous chemistry is utilized: (1) to extract metal values from an ore or an ore concentrate, (2) to purify the metal extracted, and (3) to recover that metal either as a metal or as a metal chemical which can be further processed to the metal itself. Hydrometallurgy has an important role to play in the mineral industry largely because pollution problems are easier to control when the pollutant is in the form of an aqueous solution or a solid rather than in the form of a high temperature gas as is the case in pyrometallurgy. In addition, hydrometallurgy provides a means of processing nonferrous metal oxide minerals whereas pyrometallurgy can be used for sulfide minerals. In the processing of some metals, such as aluminum and tungsten, a combination of hydrometallurgy and pyrometallurgy are used to extract, purify, and reduce the metallic chemical compound to metal. In others, such as copper, nickel and cobalt, part of the purification and the reduction can be done electrochemically, thus entirely avoiding high temperature processing until the metal must be melted, alloyed, and cast.

While the pollution abatement concern of recent years has spurred technological innovation in hydrometallurgical processes and numerous commercial installations have been made, there still remains much to be learned to make hydrometallurgy a viable technology. Little work is being done today on the very bases of the technology--inorganic chemistry and inorganic unit processes. The field of solvent extraction (more correctly, liquid-liquid ion exchange) has been developed almost totally by the national laboratories (Oak Ridge National Laboratory for the most part, for uranium processing) and by the chemical companies. The mineral industry has largely participated in this technology development through applications testing work. The whole field of low-grade-ore processing looks toward hydrometallurgy, in one form or another, for the answer to its problems. More specific chemical leach reagents and solid and liquid ion exchange reagents must be developed and low cost methods of processing large quantities of solids and slurries must be developed if the technology is to be useful under the operating conditions anticipated for the future.

- *It is the opinion of the Committee that research is needed in the basic inorganic chemistry and in the unit processes which form the foundation of hydrometallurgical processes to support the development of operations:*

  a. *that are more economical in the use of energy and energy-intensive chemical reagents,*

  b. *that exact a high recovery of valuable metals particularly when applied to low-grade and refractory ores, and*

  c. *that provide for the safe, chemically stable disposal of waste materials.*

Two specific applications of hydrometallurgy, dump and heap leaching and in situ leach mining deserve special discussion as their technology involves common principles which are somewhat different than a leaching reaction conducted in a reaction vessel.

In dump and heap leaching a low-grade ore may be processed by placing the coarsely crushed ore in a dump or heap where a leach liquor is passed through the granular material by gravity. The liquor dissolves the valuable metal from the rock and the enriched liquor is processed to extract the metal; then the depleted liquor is circulated back through the heap or dump. In many cases, the leaching operation is slow and inefficient. Research is needed to understand better the chemical reactions between leachant and mineral constituents in the rock, the flow of the liquids in crevices in rock, and the nature of the flow of the leaching liquids down through a granular bed of coarsely crushed ore. Information of this type is needed to support the development of improved methods for heap and dump leaching of low-grade ores.

The application of in situ leach mining potentially should reduce significantly the capital costs and possibly the operating costs of the facilities employed for producing metals from low-grade ores. Thus it offers the possibility of equalizing the costs of domestic production of a metal from a low-grade deposit with that of a foreign producer using conventional technology with relatively high-grade ores. It should also permit the mining of relatively small and deep deposits and should avoid some serious problems with the environment that are encountered with conventional mining and metallurgical operations.

As yet, in spite of continuing research programs, relatively little is known about the technology of in situ leach mining of metal-bearing minerals. Some major areas in which fundamental information needs to be developed are: the chemistry of leachant-rock and leachant-mineral reactions and the permeation of solutions and gases through tight rock structures at elevated temperatures and pressures found in deep ore bodies. Also needed are means for developing detailed information on the geology of formations deep in the earth. Major technical problems also require attention. Some of them are: design of well fields and management of the circulation of solutions and gases in deep-seated geologic structures; the outflow of leach solutions and gases from the volume of ore being leached and the inflow of groundwater; means for determining details of the structure of an ore body and for monitoring the progress of the extraction process; and development of reliable materials and equipment for handling highly corrosive solutions at high pressures and relatively high temperatures. Attention is also needed on the problem of how to avoid contamination of aquifers which may be near the ore body being mined.

- *The Committee recognizes that there is yet much fundamental information to be gained before in situ leach mining and heap- and dump-leaching can be practiced efficiently. Some of the major areas for research attention are:*

  a. *the study of the chemistry of leachant-rock and leachant-ore mineral reactions. Needed here are low cost leachant systems which react only minimally with host rock minerals but specifically with ore minerals leaving behind no insoluble products of reaction, and*

  b. *the study of the permeation of solutions and gases through tight rock structures and through beds of broken solids for the purpose of predicting and controlling the movement of leachant solutions.*

Additional Considerations. One area of particular concern in both pyrometallurgical and hydrometallurgical processing is the treatment of minor elements in mineral processing and metals extraction operations. These elements may be valuable constituents such as the precious metals, or they may be undesirable constituents because of their deleterious effects on the product, or because they may contaminate the environment if they escape from the processing system. The behavior of these elements in a given chemical process cannot be predicted with any degree of certainty because the details of the chemical nature of many processes are not well understood, nor is the chemical behavior of many of the minor elements or of compounds and phases containing these elements. Knowledge of this behavior is essential for the minor elements which are to be recovered as co-products in a processing stream, or which are contaminants in the waste products. These elements may be of great importance regarding pollution of the environment.

- *The Committee perceives a need for a better understanding of many of the potential pollution problems of extractive metallurgical processes as new ores are utilized and as new processes are practiced. Such concerns are:*

  a. *the fate of trace elements originally present in the ore which potentially could be hazardous,*

  b. *the development of methods of removing potentially hazardous trace elements from the process stream before they contaminate the environment, and*

  c. *the possibility of economically producing byproducts and coproducts from complex ores and from coal combustion products in the form of ash and scrubber mud.*

Lastly, in considering any change in technology in an industry such as the mineral industry it is important to plan this change within the context of the total system in which the mineral resource is extracted, a raw material product produced, and manufactured goods made from this raw material. In addition, conservation considerations dictate that resource recovery from worn out manufactured items be a consideration in the total materials cycle consideration. For example, it is conceivable that a low-grade iron ore might be beneficiated by a new process which renders it unacceptable to existing agglomeration processes or that the agglomerated product from such low-grade iron concentrates would be unsuitable for feed to existing blast furnaces. In such a case, there would be a definite need for establishing a strong interaction between the beneficiation and agglomeration technology developments to provide a suitable feed for use in blast furnaces. Another example might be the development of a process for direct smelting of alumina and silica to produce an aluminum-silicon alloy. Such a process would drastically lower the energy requirements of the conventional aluminum-silicon alloy production process and perhaps the capital cost too. But the development of such a process should be performed with the end users of such an alloy in mind in order to assure that the product produced by the new technology actually serves the purpose intended.

- *The Committee emphasizes the need to consider the interaction between the development of new mineral resource technology and the actual utilization of the raw materials produced by the new technology.*

CHAPTER 2

CONSTRAINTS TO TECHNOLOGICAL INNOVATION IN THE MINERAL INDUSTRY

In recent years committees investigating the status of American technology from one point of view or another have concluded that many European countries and Japan have advanced in their rate of technological achievement at a far faster rate than has the United States And, in truth, the latest report of the National Science Board--Science Indicators 1974--gives several arguments for this (NSF 1975). The conclusion is that more science and technology is necessary in the United States. Little attention is paid, however, to the methods whereby technology can be implemented. Even less attention is paid to the forces or constraints which may exist (including industry-government-academic relationships) to impede and interfere with the utilization of the technology already in existence or that which would be developed under a variety of recommended programs.

Numerous factors influence whether or not technological innovation--the process by which new ideas are translated into productive capability--can occur or, if it does occur, what form it will take. For example, one familiar with steel making facilities in the United States need only visit a new Japanese steel plant to recognize that whatever barriers or constraints which might exist in the United States to innovative steel making either do not exist or are substantially less operative in Japan. Japanese steel plants are the most modern in the world today. This is not only because their oldest facilities generally do not predate the post World War II reconstruction, but also because there is a high level of innovative activity present in Japan today in this industry. The underlying cause for this innovative activity appears to be a national commitment to build and to maintain the most competitive steel industry in the world. That national commitment in Japan has substantially reduced the financial, organizational, governmental, and technical barriers which traditionally impede technological innovation. It is interesting to note, however, that while Japanese steel making (processing) leads that of American industry, because of the lower level of domestic market competition in Japan, steel product innovations lay behind our own. Thus, the differences in the competitive nature of the steel industry in Japan as contrasted to those in the United States have caused innovation to predominate in separate areas of the industry in each country--steel making in Japan and product development in the United States.

Many comparisons have been made regarding the utilization of advanced technology by the Japanese and American metals producing industries. In recent years these industries in Japan have incorporated the latest technological advances in well-designed plants and facilities. In particular, newer plants for the production of zinc, copper, and steel are outstanding in such matters as the process technology employed, plant design and layout, and means for protecting the environment. In most instances, the American industrial counterparts have access to essentially the same scientific resources and technological base. However, it is apparent to the Committee that there are major differences in the two countries in the means and methods by which laboratory results and new concepts are incorporated in process design, the methods by which pilot plant results are scaled up, and the manner in which the engineering of facilities is carried out and, ultimately, in the way in which the project is finally implemented. In general the mineral and metals processing industry in the United States appears to be much slower in utilizing new processes and practices than is the case in Japan. This conclusion is drawn from observations during visits to Japan, papers presented by Japanese at professional meetings in the United States and the present international competition in metals and mineral products. One reason for this may be the number of trained metallurgical engineers in Japanese industry. Japan, a country with a population one-fifth that of the United States produces as many metallurgical engineers per year as the United States Nearly all of these graduates go into the metal-producing industries.

Arthur D. Little, Inc., in a recent report to the National Science Foundation, identified seven major barriers to technological innovation in American industry as a whole (Arthur D. Little 1973). The Committee found that several of these are significant factors responsible for innovation deficiencies in the mineral industry. Those barriers which the Committee highlighted from the Arthur D. Little report as being particularly applicable to the mineral industry are: finance, government policy and practice, markets, organizational structure and behavior, and technology. In addition, the Committee has also identified the limited availability of technically trained manpower as a constraint. The Committee also found that, in some cases, an interrelationship exists between two or more barriers such that a distinct isolation of single barriers cannot be achieved. Thus, perhaps it is incorrect to attribute deficiencies in innovation to any one barrier but, rather, it is more accurate to regard the collective influences of the barriers identified. Similarly, it is difficult to attempt to assign a Severity of Barrier Factor, as was done in the Arthur D. Little study, whereby a hierarchy of barriers might provide a priority for attention.

MINERAL COMMODITY MARKETS

The mineral industry, in all of its ramifications, is basically a commodity industry. It provides the raw materials and fuels for the remainder of industry. Its products are sold on a world-wide basis under prescribed specifications as to form, composition, and sometimes, purity. Most of its products are sold on a contract basis at prices tied to world market prices. Thus, the price structure of most mineral commodities is not within the control of American companies nor of the United States government. Except for differences due to shipping costs, mineral commodity prices are generally established in international markets. These markets reflect the supply and demand conditions on a world-wide basis and often are caused to vary by political forces as well as true market forces. Further, as has been discussed by many mineral economists, mineral commodity markets tend to be both inelastic and imperfect because they do not respond in a direct way to the normal supply/demand relationships of a free market and they offer a severe barrier to entry by new producers. There are several reasons for this: (1) A consumer does not "demand" a mineral commodity as such (iron ore, for example), rather, he demands the object in which the mineral commodity is used (an automobile, for example); (2) the cost of that mineral commodity becomes "lost" in the value-added-by-manufacture of the product (for example, a 50 percent increase in the price of ferrochrome might change the price of the stainless steel in which it is used by only 5 percent and, this increase in cost will have a minuscule effect on the cost of the automobile in which the stainless steel is ultimately used); thus, once a raw material demand is established a very substantial price change is required to change its consumptive pattern; (3) on the supply side, the limitations of the production capacity of the known and developed resources tend to limit the supply capability in the short run regardless of price; (4) further, even in the longer run, supply is largely controlled by existing producers because of the very high cost of finding a competitive ore deposit, the high cost of plant investment, and the long length of time required to find the ore deposit and bring it into production; and (5) even on the downward side of the market, the supply is inelastic due to the large component of fixed cost in the production of minerals causing the company to continue production in the face of falling prices to the extent that out-of-pocket production costs are recovered.

- *The Committee concludes that the very special nature of mineral commodity markets--their international nature, the imperfectness of short-term supply and demand forces and the inability to fully adjust, even in the long term, to supply and demand forces--is itself a constraint to technological innovation in the industry. Because of these forces, there is no advantage to the mining company from technological innovation other than to maintain an economically competitive position through the reduction of costs. The nature of the market dictates conformity of operations, thus providing a barrier to technological innovation.*

FINANCIAL CHARACTERISTICS OF THE INDUSTRY

That portion of the mineral industry which produces the major mineral-based commodities is capital intensive and most operations require large blocks of capital. The needs of a modern society and the scarcity of small high grade ore deposits has forced mining and mineral processing into large scale operations requiring hundreds of millions of dollars of capital investment per operation in order to be competitive. In recent years the requirement to meet environmental standards has imposed additional capital costs on mineral industry operations which increases further the investment cost per annual ton of product output. The inertia of large amounts of invested capital operates in two ways: (1) it preserves the status quo because capital is already invested and must be paid off and (2) it precludes the development of new technology because of the risks involved in installing new, unproven technology to either replace worn out productive capacity or to supplement existing productive capacity. Thus, invested capital produces a "flywheel" effect which tends to perpetuate existing technology. In addition, the costs of proving new technology on the scale required to yield valid results are frequently prohibitive to the development of that technology. In a smaller way, the high cost and the durability of mining equipment also inspires a slow rate of substitution for newer designed models.

- *The Committee views the capital-intensive nature of the mineral industry as a major deterrent to technological innovation. Existing investment in productive capacity deters new developments and the high cost of proving new technology on a scale large enough to be meaningful also discourages new developments.*

The mineral industry, like much of the heavy industry of the United States, is finding it increasingly difficult to raise the capital needed for new projects. Increased costs of capital goods, heavy demands for capital investment in environmental protection equipment, and the low profit margin have increased the debt-to-equity ratio of most mining companies to the point that increased financial resources are becoming more and more difficult to find. Further, as will be discussed later in this report, the production cost actually exceeds today's market price for many mineral commodities if new investment must be made in productive capacity. This not only discourages new investment but it discourages the development of new technologies even if those technologies themselves can be used to reduce capital investment costs.

- *The Committee is of the opinion that the heavy financial requirements of the mineral industry today and the current status of the mineral market are major constraints to technological innovation. When a company cannot see its way clear to fund a project employing new technology, it tends not to attempt to develop the technology in the first place. Further, under today's market conditions for a number of mineral commodities, it is clear that technology has not been able to reduce the capital cost of production sufficiently to overcome today's problems, let alone risk the expenditure of funds to overcome tomorrow's problems which are as yet not clearly defined.*

COMPANY ORGANIZATIONAL PHILOSOPHY

Many companies which comprise the mineral industry are neither staffed nor organized either in operations or management to be technologically innovative. This reflects an organizational philosophy which is itself a barrier to technological innovation. Many companies in the mineral industry have grown accustomed to operating with a minimum of trained professionals in their operations. Often a single trained and experienced mining or metallurgical engineer per shift or less is sufficient to keep an operation running. Such a practice leaves little time for trouble-shooting let alone time for adopting something new into the operations. Further, many companies in the mineral industry tend not to encourage on-going technological education of their personnel nor do they seem to have an insight into the importance of attracting and retaining capable young people into their organizations. A strong contrast can be seen between the policies of Japanese steel companies, where top technical management has a strong voice in the operation of the company, and American companies where technology is often relegated to a staff function. If the company does have a research group somewhere in its organization, more often than not the "status quo" attitude prevails when an attempt is made to shift the new technology from R&D to operations. The production-oriented management of a mining company has little time for the organizational discipline needed to bring a new project through the problems of the developmental stage. More often than not the technical management and the production management of the company see themselves on different teams and attempt to compete with one another rather than to complement one another. Thus, technological innovation has not been as successful as it might be in today's mining company.

- *In the Committee's judgement the organizational structure, management philosophy, and professional manpower component of companies in the mineral industry are geared to a conservative operational approach and that this is a serious constraint to technological innovation.*

GOVERNMENT POLICY AND PRACTICE

A mining company which tends to be oriented around specific ore deposits finds it difficult to operate in the face of uncertainty. A mining venture has one of the largest risk exposures of any activity in the private sector and anything which increases that risk tends to be a barrier to innovation in this industry. The increasing public awareness of the last fifteen to twenty years to human health and safety in industrial operations, to air and water pollution abatement, and, more recently, even to the use of public lands for mineral development purposes have all increased the level of uncertainty to decision-making in the mineral industry. Following this mood of society, the policies of the federal government and many of the state and local governments have moved from encouraging mineral development to actually discouraging mineral development. Legislation which once promoted mineral development now is becoming more restrictive in tone rather than supportive. This has not been conducive to investment in new technology. In one case brought to the attention of the Committee, the company actually felt it had traded its R&D effort for legal and legislative efforts to protect itself and to combat federal legislation and policies. By contrast, the support provided by government in "Japan Incorporated" helps to spread the risk and allows industry to think in terms of the ultimate reward in the marketing of a final product and not solely in terms of producing a particular commodity.

- *The Committee believes that the uncertainties in the current U.S. government policies, laws, and regulations are serious constraints to technological innovation in the mineral industry.*

TECHNOLOGY

The value placed on technology by the mineral industry appears to be a barrier to technological innovation from a number of points of view. First, as discussed previously, the mineral industry in general utilizes fairly uniform, well proven technology. From one company to another production of the same mineral commodity is achieved by very similar process technology. Those differences which do occur can usually be traced to differences in the ore being processed or due to differences in the age of the plants. The mineral industry, by and large, does not utilize technology to competitive advantage and also much of the new technology utilized by the industry has, in fact, been developed by equipment and other suppliers to the industry. This tends to unify the technology utilized by the industry and it also tends to de-emphasize to the mining company the role of technology in gaining competitive advantage. In addition, some of the newer technology is used by the industry (beneficiation of magnetic taconite ores, for example) when it has been developed by the state and federal governments and made available to the industry at no cost.

Other technology (flash-smelting of copper, for example) has been acquired by license from foreign sources at a fraction of the cost to develop the technology itself. This has had the same effect as supplier-developed technology on the industry, mainly, a de-emphasizing of in-house technological innovation.

- *The Committee concludes that the very nature of the technology used by the mineral industry and, in recent years at least, the fact that a significant fraction of the newer technology in use has come from outside the industry itself, constitute a constraint to technological innovation by the industry.*

MANPOWER

The anticipated increase in complexity of mineral and metal processing systems will require well-trained manpower for research and development and for operating processing systems and plants. Only a few hundred bachelors degrees are awarded in the fields of mining engineering, minerals processing and extractive metallurgy each year in the United States and only about 50 doctoral degrees. The recent fellowship program of 500 awards per year in mining and mineral fuel conservation by the Department of Health, Education and Welfare has provided stimulation for graduate educational efforts. A successful program requires that funding for research in the colleges and universities be matched with the support for stipends and tuition and the emergence of challenging career opportunities in the mineral processing industries.

- *The Committee considers that one of the constraints on the development of improved technology in the field of mineral processing and metal extraction is the shortage of well-educated and well-trained personnel. It is concluded that this shortage will persist for a number of years and that educational programs of good quality and with an engineering focus should be stimulated to meet the shortage.*

A major motivation for industry to improve its technology is to improve the working conditions in all types of operations. With the increasing complexity of all types of facilities, it is essential that working conditions be improved so that able and well-motivated people are attracted to take up work at all levels in the field.

CHAPTER 3

FORCES FOR CHANGE IN THE MINERAL INDUSTRY

It was the basic premise of this Committee that certain conditions and events which have already taken place are going to make it necessary to re-think the role of technology in the American mineral industry. These condition and events might be classed as geopolitical and environmental. In addition, the Committee has noted other conditions which are evolving in this industry and in others which will require a technological response if the industry is to continue to serve the country in its role of raw material and fuel material supply. Significant forces for change in the mineral industry, as perceived by the Committee, are summarized below.

GEOPOLITICAL AND ENVIRONMENTAL CONDITIONS

The Committee members were in general agreement that the original rationale for the Committee concern for the technological health of the mineral industry is valid, namely,

1. that uncertain political regimes and increased nationalism in much of the world will interfere with American companies' access to mineral deposits in these lands and that while many foreign governments will be seeking American capital, they also will be striving for increased value-added-by-manufacture in the mineral commodities and goods exported to the United States. Thus, ore deposits in foreign countries, which were once accessible to American companies will no longer be accessible,
2. that as known rich ore deposits are depleted, domestic mining ventures will be tending toward lower and lower ore grades, more refractory ores, and more remote ore bodies,
3. that the environmental and resource preservation concerns of society as reflected in federal and state government regulation will continue to encumber domestic mining and mineral processing operations--restricting those that exist and

preventing the establishment of others if society so dictates, and

4. that while per capita consumption of energy and raw material may decline, the general trend for the future will be continued and increasing requirements of mineral-derived energy and raw material commodities due to growth in population.

The net result of these conditions will be to require a higher level of technology in finding ore bodies, in mining minerals from the ground, and in processing these minerals to energy and raw material commodities for the supply of the American economy, all at a cost consistent with favorable competition with foreign producers and under general conditions of operation which meet sociological dictates.

- *The Committee anticipates that political uncertainties in many foreign areas will force the mineral industry to give more attention to the development of domestic deposits. The mining of domestic ores, especially those of low grade, under increasingly stringent environmental regulations will require the development of improved technology if our mineral material needs are to be met in the future.*

INVESTMENT CAPITAL REQUIREMENTS

Rising costs and increased financial risk promise a scarcity of capital in future years as mining companies are forced to compete with industries having higher returns on investment and/or less risk. The composite statistics for the nation's major steel, aluminum, copper, lead, and zinc companies show that between 1972 and 1977:

- cost of production increased by $17.2 billion per year,
- dividends to the shareholder decreased from 47 percent of net income to 40 percent of net income, and
- long term debt increased from $10.4 billion to $13.8 billion.

Mining ventures are some of the largest projects funded by private enterprise in the world. Huge amounts of capital, often on the order of $200 to $500 million per project are required. The nation's newest copper smelter, the Hildalgo smelter of the Phelps Dodge Corporation had a capital cost of $300 million--and this did not include the cost of the mine nor the mill which were already in existence. New plant investment costs are $6,000 to $7,000 per annual ton of copper. The investment costs per annual unit of copper production capability have increased five fold since 1950 and more than two fold since 1970. For companies contemplating entering this industry the debt service on their investment is as much as 49¢ per pound of copper, more than four-fifths of the present selling price of 60¢ per pound (September 1977). An average operating cost of another 53¢ per pound increased the before tax/before profit costs of the product produced to a level in excess of today's market price! Clearly, such project proposals will not attract investment in times of soft world prices and at times of uncertainty as to future restrictions on operating conditions.

The mineral industry is rapidly falling in financial arrears due to inflation, increases in costs for day-to-day operations, capital expenditures for non-productive pollution control equipment, and the additional costs of operating this equipment. At the same time there are strong pressures to hold prices of the products of the industry down because of foreign competition and government attempts to minimize inflation. The investment required for new capacity in all extractive industries has increased markedly because of inflation, declining quality of raw materials and pollution abatement requirements. Inflation has hurt the primary metals industry because sales prices have not kept up with the cost of buying new production capacity or with manufacturing costs. Although the price index briefly caught up with the construction index in 1974, the industry is still paying for overly expensive facilities purchased in the 1970-1973 period and the indices are again diverging to the detriment of construction costs. The price realized by the primary metals industry for its products has not kept pace with the investment requirement for new productive capacity; thus, the investment-to-sales ratio is rising rather than declining. If existing technology is to be used in expanding the productive capacity of the primary metals, then most metals--aluminum, copper, and nickel in particular--will require a substantial price increase. One estimate of the price required to support new production is shown in Table I. The data in Table I indicate that present market prices for the major commodities listed are not adequate to pay for new plants using the best existing technology. In addition, the commonly held fear is that new technology will be more costly than existing technology in both capital investment and operating costs.

- *The Committee expects that rising investment costs will be a major incentive for the mineral industry to seek technological change. Two avenues of approach appear to be open to the industry: (1) increase the throughput of existing processes, or (2) develop new processes which have less capital*

TABLE I Estimated Price Required to Support New Productive Capacity in the Primary Metals Using Existing Technology

	Investment Cost $/unit	Operating Cost $/unit [a]	Calculated Price $/unit [b]	Market Prices	
				July 1976 [c]	December 1977 [d]
Aluminum	2,400/annual ton	0.37/pound	0.66/pound	0.44/pound	0.53/pound
Copper	6,000/annual ton	0.53/pound	1.27/pound	0.74/pound	0.61/pound
Iron Ore (pellets)	80/annual	14.48/long ton	33.70/long ton	31.29/long ton	34.41/long ton
Lead	1,400/annual ton	0.11/pound	0.29/pound	0.24/pound	0.33/pound
Nickel	16,000/annual ton	1.17/pound	0.13/pound	2.20/pound	2.08/pound
Zinc	1,600/annual ton	0.19/pound	0.39/pound	0.37/pound	0.30/pound

[a] Excluding depreciation

[b] Including return on investment and taxes

[c] Market prices as of date of Boik and Verney paper

[d] Market prices as of date of this report

SOURCE: For the first 3 columns — Boik, B.C. and L.R. Verney (1976) Investment and Operating Costs as a Factor in Metals Availability and Price. Presentation at the American Institute of Chemical Engineers 82nd Annual Meeting, Atlantic City, New Jersey. (Unpublished Report) *cost per unit of output. These may be manifested as a short-term and a long-term approach to the problem.*

LABOR AND THE QUALITY OF WORKING LIFE

All of American industry has been experiencing gradual but definite changes in labor--numbers available to the work force; attitudes and desires of workers for type of work, safety of work place, benefits and share of the profits of their labor; and numbers of women entering the work force. Our country has seen a continual shift from unskilled labor to skilled labor. The Bureau of the Census reported that in 1974 only 7.7 percent of the work force could be considered unskilled labor whereas in 1900 15 percent was classified as unskilled. We have seen a gradual shift away from labor-intensive jobs. Farming, for example, which required 31 percent of the domestic labor force in 1910 required only 8.6 percent in 1974. Lesser numbers are entering the work force now than just a few years ago and it has been predicted that 40 percent less is anticipated to be entering during the 1980s than in the 1970s. This will lead to greater competition for the workers who are available.

Mechanization has changed the work patterns of most industries. While mechanization has partially been in response to labor pattern changes, it has itself contributed to changes in these labor patterns. Farmers, longshoremen, steel workers, and numerous others have found their working style and working conditions changed due to mechanization. While this has caused temporary unemployment in some industries, in the main it has increased the quality of employment through an increase in the skill level of the job and an improvement of working conditions.

Education has also been a major factor in changing labor patterns. The percentage of those educated beyond secondary school will increase from 18 percent in 1972 to an estimated 32 percent in 1985. In other words, by 1985 that part of the labor force with post-secondary education will have nearly doubled. One United States coal company is already encouraging its miners to have one to two years of a technology training school before being placed on the work force. Teams of such trained workers have already demonstrated improved productivity and an improved safety record over similar but untrained teams. Yesterday's immigrant unskilled laborer is already being replaced by educated sons and daughters in the labor force who are not willing to subject themselves to the low quality jobs of their fathers and mothers. Domestic servants, ditch diggers, and general laborers are becoming a thing of the past and are now being replaced with service companies or machines.

Women entering the work force both as a result of Federal Equal Opportunity requirements and as a result of making household ends meet have changed both the work place and themselves in the process. More and more work is tailored so that women as well as men can perform any job. Jobs requiring strength and endurance are rapidly phasing out. Women, finding equality are themselves becoming part of the change and seeking a greater and greater role in every facet of labor--many times proving themselves to be more capable than men in jobs requiring patience, neatness, carefulness, and knowledge.

It is generally agreed that the net result of these trends in education and attitudes of the work force is that management will have to "humanize" work and the work place itself. Dirty jobs will be minimized. Automated jobs will be out of favor, requiring the adoption of technology to people rather than people to technology. Labor expects work to be an "experience" rather than a "burden" or a "duty" and this combined with an increased mandate for a healthier, safer work phase will require improved manpower planning and, in many instances, a totally different work place concept. Furnace men in a steel mill who once tapped molten steel ladles by hand are already remotely operating mechanical tapping devices and, instead of relying on intuition and experience to determine the exact time to cease an oxygen blow as steelmen once did, these men now respond to rapid responding sensors and computers to determine the time for their response. The construction worker who once walked to his work place on the 30th floor of an office building which is under construction now rides an elevator--an elevator whose construction actually precedes the construction of the building itself.

The mineral industry has traditionally encountered labor difficulties both in terms of availability and experience of personnel. At the present time the industry appears to be incapable of bringing in young people to its labor force to balance the age distribution of its labor force. According to United Mine Workers' president, Arnold Miller, nearly thirty percent of his union's membership will be eligible to retire at the termination of their present contract with the mineral industry (Moss 1976). A recent analysis of the membership statistics of the Society of Mining Engineers of the AIME showed that approximately fifty percent of its members involved in mineral exploration and mining are fifty years old or older.

In underground mining the high turnover of unskilled miners has been one of the causes of the poor safety record of such mines in past years. Training programs ranging from formalized on-the-job training to educational institution training have greatly improved both safety and productivity. While this experience has shown the importance of a higher level of educationally-derived skills among miners, it also forecasts the need for a higher plane of work duty if these people are to be satisfied and remain on the work force. As working conditions improve, more highly skilled labor can be attracted and utilized in mining and, as was mentioned earlier, with the consequent improvement in both productivity and safety records. Through the use of mechanization, lower numbers of workers per unit of production can help to offset generally reduced numbers available in the work force as well as accommodate women in the work force.

- *The Committee foresees shifting work-force trends as an incentive to technological innovation in the mineral industry whereby the general level of work and the work place will be improved. In mining, as in other industries, the trend will be to remove the miner from the actual site of mining during the mining operation. The challenge for the industry is to utilize the flexibility offered by technology to upgrade the quality of labor's working life in order to accommodate the work force available, rather than to force the worker into the rigidities of technology.*

SCALE OF OPERATIONS

It appears that in many industries we are reaching the point of diminishing returns on the "economy of scale." To some extent transportation costs have helped to top off the size of many operations. Automobiles are now assembled at a number of assembly plants located close to ultimate markets rather than at one plant located in Detroit. Open pit mines and underground mines likewise reach a limit in economy as haulage distances from the bottom of the mine to the mill become larger and larger. Capital costs have also tended to limit the size of projects for, as costs have increased to the point that capital is difficult to raise, alternative methods have had to be sought at lesser capital cost while still preserving the profitability of the larger sized project.

- *The Committee observes that perhaps incentives for technological innovation are already present which will lead to a "technological" dependence rather than a "scale" dependence in operating a mining project in a cost-competitive fashion. By* *doing so, new opportunities will be opened for at least reducing the magnitude of the capital investment per project if not also capital investment per unit output.*

CONCLUSIONS AND RECOMMENDATIONS

The use of minerals is as old as man himself, and mining and metallurgy as a form of technology is almost as old. The mineral industry thus has a long history of evolutionary development of processes and practices based on basic principles discovered centuries ago. As ore grades have become leaner and as society's needs have become more sophisticated, the industry has accommodated to those conditions imposed upon it by new technological developments to the extent that the mineral raw material and energy needs of this country and others have been adequately met in the past. Shortages of mineral-derived goods have been the exception rather than the rule in spite of the ever growing demands of the world's people for these goods.

Now, suddenly, in the course of a very few years the mineral industry finds itself confronted with a number of obstacles to its ability to satisfy national needs--environmental protection mandates, a severe shortage of energy, restrictions on access to public lands for mineral development, and a growing nationalism on the part of foreign nations to decrease the availability of their mineral resources to United States companies. The mineral industry appears to be headed for a traumatic change because of these restrictions which, in turn, can be expected to disrupt the supply of raw materials and energy to our economy. Existing technology utilized by the industry in the conduct of its business appears to have been stretched to the limit of economic utility already and new technology to carry over into future operations does not seem to be available.

Accordingly, the Committee on Mineral Technology has concerned itself with an attempt to understand the present role and status of technology in the mineral industry. The Committee has identified a number of disincentives or constraints to technological innovation in the industry. It has also identified a number of reasons why the industry should become more technologically innovative in order to meet the future demands placed on it. The Committee generally finds that there are insufficient incentives for the mineral industry to be technologically innovative in the face of numerous constraints influencing the industry.

Those incentives which should be present within the individual companies often are not present, and those incentives which should be present in public policy, as reflected by federal and state government regulations and programs, are not present. The summation of the Committee's findings is that the rate of technological response within the American mineral industry at this time is not consistent with the demands which are anticipated to be imposed upon it. This could prove to be harmful to the individual companies in the industry as well as to the health of the American economy and security in general.

It is the consensus of the Committee that the federal government should seek ways of encouraging technological innovation in the domestic mineral industry. This is an industry which is vital to the economic and military security of the nation and must be prepared to meet the needs of the country in the future. In the absence of a national polity encouraging technological advancement, and in the face of severe operational restrictions and financial difficulties in recent years, the industry has not kept pace technologically with the demands placed upon it. While present needs are being met by retrofit technology, it is apparent that the fulfillment of future needs will be severely restricted if adequate technology is not available and the means available to place it in use. The Committee recognizes a number of reasons which justify the participation of the federal government in the stimulation of technological innovation in the domestic mineral industry. Among them are:

a. where costs of R&D are high and benefits per firm are small, but aggregate social benefits are high, as for example: where the solution of a problem requires a very long lead time or requires a major departure from current practice, and where political and economic risks are high and beyond the capacity of the individual firm,

b. where research and innovation are required to meet socially imposed standards--e.g. environmental and safety measures--government supported R&D will help keep the market competitively healthy,

c. where foreign countries have a monopolistic control over certain vital minerals and can restrict supply and/or increase prices beyond reasonable levels; for example, bauxite and chromium,

d. where rapid industrial responses are necessary and only a limited number of professionally trained people are available public good is likely to be best advanced by coordination of research efforts and concentration of research competency, and

e. where important national security interests are involved.

While the Committee believes that government has a valid role to play in the development of new mineral technology, whether through the establishment of positive incentives for industry or through direct participation, it firmly holds that such technology must be capable of being implemented by American industry. The need is clearly for technology which can be readily implemented by the private sector and for federal policies conducive to the generation of capital for expenditure on new technology and plant investment in the private sector.

In considering technology programs, only a minimal technical effort should be expended on patching-up existing and old or potentially obsolete and costly procedures and processes. A maximal technical effort should be devoted to a re-evaluation and modification of existing procedures and processes and the rapid development of new procedures and processes which will satisfy likely future conditions under which the industry will be required to operate. Such technology programs should specifically involve teams of scientists and engineers drawn from industry, universities, and the federal government in order to take maximum advantage of the scientific and technical skills available and to facilitate the transfer of technology to the private sector. Such programs could be conducted in the form of institutes specializing in the technology of one or another mineral commodity and/or could be in the form of industry-operated demonstration programs which are jointly funded by industrial consortia and the federal government with the cooperation of university groups. Federal policies promoting innovation in the industry could embody incentives such as tax credits for new investment in plant and equipment as well as for R&D expenditures related to the development of new technology. Ways should be sought which will increase the protection offered by present patent laws, which will permit consortia technology development without infringing on the antitrust policies of the federal government, and which will encourage both industrial and academic participation in R&D.

- *The Committee recommends the adoption of federal policy and the establishment of federal programs for the purpose of enhancing the technological capability of the domestic mineral industry in order that this industry may more effectively provide for the material and energy* *needs of the country in the face of present and anticipated future restrictions to the timely supply of mineral commodities. Such policy and programs should both establish a positive incentive for technology development and application within the industry as well as establish programs within government for direct participation in mineral technology development. Such policies and programs should:*

1. *provide for the professional development of competent research and development personnel*

   a. *through the use of teams of mineral scientists and engineers comprised of representatives from industry, academia, and government,*

   b. *through the establishment of mineral institutes at qualified academic institutions where technology development and professional manpower development simultaneously take place.*

2. *provide for the development of new technology*

   a. *through the establishment of demonstration projects in selected areas of technology, particularly those where the overall interests of society are to be served, operated by industry, jointly funded by industry and government with the professional participation of mineral scientists and engineers from industry, academia, and government*

   b. *through the legislative provision for the establishment of single industry consortia which exist to develop major new technologies for that industry's use for society's benefit.*

3. *provide incentives for the application of new technology in the mineral industry through the establishment of:*

   a. *tax incentives on investment in new technologies,*

   b. *increased protection for novel technologies beyond that offered by present patent and antitrust policy and practice,*

c. *government purchase programs based on the use of new technologies using low-grade or refractory domestic ores in the production of goods purchased.*

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