The Queen's Symposium: Trends in the Mineral Industry in the next Decade

Introduction

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At the time of writing, international events and national policies for non-renewable resources are in the process of rapid evolution, frequently appearing as sudden crises. This is particularly true of fossil fuels, brought on by the recent actions of the Middle East oil producing countries. That such events might come to pass so soon was foreseen by only a handful of individuals, although a growing number had been anticipating the future and warning against the consequences of ever-growing rates of consumption.

Among these has been Dr. King Hubbert, research geophysicist for the United States Geological Survey and Past President of the Geological Society of America, who has for many years carefully studied world fossil fuel supplies. These studies culminated in a series of his papers which demonstrated, among other things, that at current rates of discovery and production of natural gas and crude oil, the U.S.A. may have passed its peak. World production of fossil fuels of all kinds may last for only a few hundred years. Dr. Hubbert presented these ideas most forcefully at a Symposium on "Trends in the Mineral Industry in the Next Decade" which was held at Queen's University on October 26, 1973 to mark the openings of Goodwin Hall (Mining Engineering) and the Bruce Wing and Hawley Laboratories (Geological Sciences). The details of his analysis have been published under the title "Man's Conquest of Energy: Its Ecological and Human Consequences" in T.I.D.-25857 of the U.S. Atomic Energy Commission, Office of Information Services.

The Symposium was opened with a paper by Dr. Robert Legget, another past president of the G.S.A., and one time professor of Civil Engineering at Queen's but best known as the first Director of the Division of Building Research of the National Research Council. Dr. Legget's paper "The Challenge of the Future for the Earth Sciences" forms part of this issue of *Geoscience Canada*. Dr. Legget draws attention to the growing inter-relation between mining and civil engineering and that in the future, mineral development is going to mean not only finding and extracting ores from the earth's crust but also the rehabilitation of the surface of the land where it has been disturbed. He draws attention to the importance of industrial minerals and building materials and the relentless consumption brought about by the population explosion and the acceleration of urbanization.

Included also in this issue of *Geoscience Canada* is the paper presented by Mr. John Kostuik, President of Denison Mines Ltd., entitled "Mining in the Next Decade". Mr. Kostuik refers to the Club of Rome activities and points out that spokesmen for the mining industry, while recognizing that mineral reserves are finite, believe that resource requirements may be met by improved technology; substitution trends; rising metal prices and lower grade deposits. He makes some interesting comments about mining's public image, the preference of the work force for urban life and the research and development necessary to bring about the required new technologies.

Dr. Louis Renzoni, Vice President of the International Nickel Co. of Canada Ltd. for Special Technical Projects, follows with a similar analysis of "Mineral Processing in the Next Decade". He points out that technology has progressed to the point where non-polluting plants can be built and that henceforth capital costs of any new project will include that required for environmental safeguards. He also places most metals in the category of renewable resources (more renewable than trees) because they can be recycled and need not be lost. Dr. Renzoni sees considerable hope for the recovery of nodules from the sea floor, but concludes that progress in process metallurgy may not be spectacular but, rather, slow and steady.

The Symposium concluded with an address by the Hon. Donald MacDonald, Minister of Energy, Mines and Resources, who announced the signing of an agreement between the Government of Canada, the Mining Association of Canada and Queen's University to establish a Centre for Resource Studies. He drew attention to the extremely complex problems arising because of the interaction of the scientific, technological, economic, sociological, environmental, financial, legal, political and international aspects of resource development. The Minister's main message was that mineral policy must evolve to reflect how Canadians perceive their mineral endowment as supportive of their aspirations for a strong economy, a clean environment and an increasing degree of national autonomy.

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The Challenge of the Future for the Earth Sciences

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The challenge of the future is rightly and properly the dominant thought in the minds of all of us who are participating in this Symposium. It is only natural that the challenges of the years immediately ahead should first come to mind. But to set the scene for the proceedings of today is a three-fold task—to look back briefly, to appreciate what the new facilities at Queen's will mean today but also, and above all, to peer into the unknown of the future to see if there are guideposts that may already be discerned.

Let us, then, take a quick glance backward, appropriately so today since it will be exactly eighty years ago on Tuesday next (October 30, 1893) that the doors of the old School of Mining were opened to its first students and Dr. Goodwin started his leadership of this new venture. Its full and official title—let us not forget—was the "Kingston School of Mining and Agriculture". It was developed in association with Queen's but could not be an official part of the University because of the close ties between University and Church, ties that would not be severed until 1912.

Carruthers Hall was leased by the School of Mining from the University and here started the great work of which we are thinking today. It was then described as "a *complete* scientific education of both a theoretical and practical character to young men studying mining engineering and to provide theoretical and practical instruction in subjects pertaining to modern agriculture." The need for a school of mining arose from the fact that no such facility then existed at Toronto, or elsewhere in the province.

An early recruit to the staff of the School of Mining was Alexander James Macphail. "Sandy" was a remarkable man, a distinguished soldier, a poet, editor of the *Queen's Quarterly* for many years as well as being Professor of General Engineering, a chair peculiar to Queen's. It is well that we recall his name also today. I think that he would have appreciated my turning your thoughts now to the future by quoting from a letter written on January 7, 1866 by John Stuart Mill: "There is now no place left on our planet that is mysterious to us, and we are brought within sight of the practical questions which will have to be faced when the multiplied human race shall have taken full possession of the earth (and exhausted its principal fuel)." Percipient as those words were in their day, and unheeded, how much more relevant they are to our situation today, with all parts of the planet photographed from orbiting satellites, population increase seemingly uncontrolled, and not only fuels but some minerals already becoming critically scarce. We cannot, we must not ignore what is taking place on our planet; my first suggestion therefore is that the students of tomorrow must realize that minerals are a wasting asset.

This is a term regarded with disfavour in some quarters. Indeed, there may be some who consider that such a concept has no place at all on an occasion such as this. On the contrary, I submit to you that this is where our thinking about the future must start. Nobody can dispute the fact that minerals are accurately described as a non-renewable resource. Once taken out of the ground, they will not be replaced in the foreseeable future. They may be reclaimed after use by what is now termed recycling but the quantity so regained is still almost negligible when compared with the quantities of minerals and mineral products that are consumed. To some, this is alarmist, defeatist talk; one can hear serious statements to the effect that new mineral resources are being discovered at the same rate as those already known are being used up. Would that it were so—but if even it were correct, it does not alter in the slightest degree the fact that minerals taken out of the ground will not be replaced. The optimists will point to the phenomenal new mining developments in Australia, developed during the last fifteen years; to the discoveries in Ireland in which Canadians have played so remarkable a role; to the Welkom Mine in South Africa; and to such recent discoveries as those in the eastern Arctic of Canada. The importance and significance of these and similar developments of the last few years is not to be minimized. Rather it is to be hoped that similar new developments will be seen in the years immediately ahead. Even they, however, do not change the overall general picture.

One of the first public documents to call attention to the overall mineral situation was the Paley Report of 1952. This was a masterly survey prepared under the direction of an outstanding U.S. group headed by William S. Paley. It attracted much attention when published because it was so striking a warning of the rate at which strategic minerals were, even then, being used up. Today, it is seldom mentioned and even when it is referred to, this is usually done in a slightly derogatory manner because the estimates that it presented for mineral production and consumption for the year 1975 have already been exceeded in many cases. What seems to have escaped general attention is the fact that this defect in estimating is clear evidence that the rate of utilisation that so alarmed the Paley Commission has greatly accelerated in the years since their report was issued. It is well to remember that in the period of thirty years following the first world war, the United States alone used up more minerals than the rest of the world had used throughout all of recorded history. And the rate of consumption has accelerated since then, to such an extent that a recent estimate showed that the annual U.S. per capital mineral consumption is now about $40 as compared with an average of less than $1 for the under-developed world.

The main criticism of the Paley Report that can be made today is that perhaps it was too early. Memories of the war years still dominated thinking and its predictions seemed to many at the time to be much too alarmist. Let us, then, look at the situation today. One recent estimate suggests that world consumption is increasing at a rate of five per cent per year. Another forecast is that mineral consumption will have trebled, for the world as a whole, by the end of the century, now only 27 years away. In 1968, a U.S. Conference was told that mineral consumption in that great land may double by 1985, and double again by the end of the century. Contrast such estimates with the fact that today the United States uses more silver for photography alone than its entire domestic production, that already it is importing about one-third of all the iron ore it needs for its great volume of iron and steel production, and that it produces within its own borders only thirteen per cent of its requirements of bauxite and alumina for aluminum production.

This is the overall situation in which the students of today and tomorrow will be starting their careers. It will be said that I have used only figures for the United States, that the situation in Canada is far different. It is different in degree but not in fundamentals and in any case one may well ask if this country is to continue exporting its raw ore for others to use. Canada has abandoned mines just as does the United States and nobody who has seen them can ever forget that in mining we are dealing with a non-renewable resource. There will assuredly be new discoveries of valuable ores, but one cannot be too "starry-eyed" about this prospect if only because so much of the land area of Canada has been glaciated so that it has little or none of the soil cover beneath which some of the most spectacular recent discoveries in other lands have been made, utilising modern prospecting techniques. And any suggestions that the North of Canada will be found to be a "treasure house of untouched mineral resources", as the northern part of Siberia has already been proved to be, merely reflect wishful uninformed thinking.

Is this defeatist talk? Not at all, it is but a brief realistic assessment of the mineral situation with which the students to be trained at Queen's (and elsewhere) will have to deal. Clearly, it will call for even greater skills than ever in the past, based upon a sound appreciation of the economics of mineral development and an underlying basic philosophy that will allow to be forgotten neither the fact that minerals are a non-renewable resource nor the equally vital principle that all citizens must be "stewards of the land" that is theirs. It is already evident that the ever-increasing demands for minerals throughout the world mean that ores of much lower grade than have previously been thought of as economic must now be worked. Many examples could be cited to show that this significant development has already started. It means, inevitably, that far greater volumes of material must be handled in order to win the same amount of ore than ever in the past. These vast quantities of waste material must be disposed of and this at a time when conservation of the environment has, at last and most fortunately, come to be recognized as essential. These are problems new to mining. They suggest two aspects of training and education that will call for increasing attention.

It is inevitable that the use of progressively lower-grade ore bodies will mean a corresponding increase in the amount of open-pit mining. The disfigurement of the landscape that such mining operations cause needs no elaboration from me but it is something that will be, from now on, under steadily increasing public control. In many parts of this continent it is a problem that is already being tackled. It has been estimated that well over 5,000 square miles of the land surface of the United States has already been disturbed by open-pit mining, about one-quarter of this being for coal. Some of the greatest of all open-pit operations have been for copper ore; it is significant that not one open-pit copper mine has yet been rehabilitated. Mineral development in the future, therefore, is going to mean not only finding and extracting ores from the earth's crust but also the rehabilitation of the surface of the land where it has been disturbed.

This new responsibility goes far beyond what is normally thought of as mining engineering. It involves much civil engineering, especially in handling large quantities of material and in ensuring the stability of slopes whether in excavations or of refuse piles, temporary though these may be. Construction of such artificial facilities as islands in the sea has already featured some recent mining developments. There are bound to be more demands for the expertise of the civil engineer working in association with mining engineers for the successful exploitation and rehabilitation of mines that are yet to be. And this new type of activity is not something to be "handed over to a contractor", excellent as is the work of Canadian contractors. It requires the independent assistance of the professional civil engineer first, for study of the problems involved, assessment of the economics of alternative solutions and only then the preparation of contract documents and design drawings upon the basis of which contractors may be asked to submit tenders for the execution of the work. The success of the unique Steep Rock Iron Mines development was due, in large measure, to the excellent preliminary civil engineering work—in closing off the Lake and diverting the River that previously flowed through it, prior to the pumping down of the lake waters—carried out by eminent consulting engineers, the works executed by contractors of similar standing.

This significant trend in mining engineering has been recognized by at least one of the major Universities of the United States which has recently combined departments and formed a new division of its engineering faculty known as the Department of Civil and Mineral Engineering. The same desirable results can naturally be obtained without such internal rearrangements if the proper, and essential, inter-disciplinary spirit pervades all the work of an engineering faculty, as has been the case at Queen's University. The purely artifical division between rock mechanics and soil mechanics that still unfortunately persists in some countries (of which Canada is one) must disappear, a development in which the word *geotechnique* can aid so much. There is so much to be gained by the closest cooperation of mining engineers with their professional brethren in other parallel branches of engineering, and nothing to be lost, that one may wonder why it should be necessary to speak of this as a desirable "new development"—but it is.

I sometimes find myself wondering, in this connection, how many Canadians know of the connection of Thomas Edison with mining in Canada. His experience provides a cautionary tale that every mining graduate should know. Edison first visited Sudbury in 1892 and was attracted back again in 1901 after he had seen a block of nickel ore at a Buffalo Exhibition earlier that year. He needed nickel for some of his experimental work. In a search for it, with a large party, he made use of a dip-needle and located what appeared to be an ore body. This was in one of the sink-holes at the eastern end of the great basin. Men were put to work excavating a shaft and managed to carry it to a depth of 35 feet. There they ran into so-called "quicksand"; not knowing how to deal with this, the shaft was abandoned and a little time later the Edison crew left Sudbury. In 1915 valuable nickel ore was found just 15 feet below the level of the bottom of the Edison shaft and only 20 feet away. One of the great "ifs" of Canadian mining is posed by the question of what the Sudbury development would have been like if Thomas Edison, brilliant man that he was, had read even a little of the history of civil engineering and so found out how Robert Stephenson dealt with water-saturated sand ("quicksand" to the uninitiated) in the construction of the Kilsby Tunnel in England in 1841. The knowledge was there; it was not used. Again we are reminded that communication is a two-way process.

Mention of sand serves also as another reminder—of the importance of industrial minerals, the Cinderella of the mining industry if I may so describe them, hastening to add—a rather buxom Cinderella since the value of sand, gravel, crushed rock, cement, lime and clay products represents about 12 per cent of Canada's total mineral production. This figure may be compared with nine per cent for all the so-called non-metallics, 28 per cent for fuels, and about 50 per cent for the metallic ores which loom so large in the mind of the public. Do we find the same kind of phenomenal increase in demand for industrial minerals as for metals? Assuredly we do, as great if not indeed greater, so rapid is the growth of cities throughout the world—and the industrial minerals provide some of the most important of building materials, the materials of civil engineering. Let me illustrate the gravity of this part of our overall picture by giving you figures for the situation in southern Ontario. In 1945 when the population of the area was about four million, a total of almost 14 million tons of sand, gravel and crushed rock was produced and used. Today, with a population just about double, the corresponding quantity is about 120 million tons. The significance of these figures is shown if we consider the per capita use of these materials, so mundane when compared with gold and silver. In 1945 we used 3.41 tons per head. Today we are using over 15 tons per head, per year. And if anyone should be thinking that they, personally, do not use any sand, gravel or crushed rock during the year, let me remind you that these are the materials that are used for you in the construction of our highways, of our airports and, above all, of our cities. They, too, are minerals being used up not only at an ever increasing total quantity but increasing at about twice the rate of the increase in total population, staggering though that is in itself.

The future presents its challenges here also, challenges that must be faced since the increase in the demand for industrial minerals is inexorable; it cannot be halted. Put aside all thought of the small gravel pit in the back-lot; we are talking in terms of major operations, of mining on a vast scale. The demands are many; as but one unusual example, the railways of Canada use something like five million cubic yards per year of industrial minerals as ballast for their tracks. So bulky are the materials that, when they are not to be processed where they are excavated (like cement), the cost of transport may well exceed the initial cost of the material. The direct consequence of this is the economic desirability of locating quarries and sand-and-gravel pits as close to centres of demand as possible, as close therefore to cities and towns as can be done. Around almost every municipality can be seen mute evidence of this economic necessity now, at last and fortunately, being controlled for public benefit through the new Pit and Quarry Act of the Ontario Legislature. The sand-and-gravel pits near towns, however, are usually pits that have been "worked out", so urgent has been the demand for such easily accessible supplies, with the result that the newer sources of supply are unavoidably far distant from the places of use, with consequent increased cost. Toronto, for example, has now been drawing supplies of aggregate for concrete from places as much as 80 miles away. In the older countries of Europe, the supply of sand and gravel has become so critical that large quantities are now being obtained from the bed of the sea, by dredging. As much as 10 per cent of the total consumption in Great Britain now comes from this source.

This is one example of mining from the bed of the sea that is already being actively pursued and would seem bound to increase, provided that all due precautions are taken to ensure that Nature does not take its revenge by corresponding shore erosion. Even here, therefore, the most careful advance studies are essential before any such interference with a natural deposit can safely be started—another example of inter-disciplinary work initiated by mining. The fact that such supplies have to be used will show clearly the value of deposits of sand and gravel on land that are adjacent to building sites. It is absolutely essential that no deposits of useful sand and gravel should be covered up by urban developments because of inadequate preliminary sub-surface investigations. This is such an obvious requirement that its mention in this context might seem to be rather foolish but there are, unfortunately, all too many examples of splendid and extensive deposits of excellent sand and gravel now covered up by city streets and so unavailable for use. I could, for example, take you to a virile modern North American city and actually show you evidence of the estimated $15 million of sand and gravel located beneath its streets but now naturally unavailable for use. The earth sciences have, therefore, a vital part to play in the planning of all future urban developments, whether it be the start of new towns, the extension of existing municipalities or the rehabilitation of older parts of larger cities. This prospect may seem to be somewhat far removed from the future of mining engineering but enough has probably been said to show that, as with all branches of modern technology, mining developments cannot any longer be considered on their own. They form a part of the fabric of civilisation as we know it and so must be fully integrated with it.

Let us, however, return to the more restricted field of materials, metallic and non-metallic, that are the result of mining activity. Think only of the materials normally used in building—concrete, wood, steel and aluminum being the principal so-called structural materials used to build the cities of today and the multitude of associated services that we now regard as so essential. We have seen something of their recent growth. Will the demand for them continue at the same frantic pace? Let me answer this question by quoting from an official Press Release of the U.S. Departments of the Interior and of Housing and Urban Development, issued in 1969. It states that "by the year 2,000, major urban regions will cover about 340,000 square miles, as compared to the present 200,000 square miles." This official estimate is, therefore, that by the end of the century the United States alone will require 140,000 square miles additional to that already in use for new urban development, the extension of existing cities or the formation of new towns. What does 140,000 square miles represent? An area equal to the combined areas of England, Wales, Scotland and Czechoslovakia combined. The demand for the products of the mines will seem to be almost insatiable, but it must be met.

An occasional comment on this explosive situation is that, if only because of the great demands ahead, there is bound to be a "breakthrough" in building practice. This comment is often coupled with the suggestion that new materials will automatically be developed to provide a substitute for the materials upon which we rely at present, materials the supply of which is so clearly limited.

New materials? I wonder where from. All the metals have now been discovered; their properties are known. It is a remarkable fact that if we take what may be called the specific strength of all the common structural materials—the strength expressed as Young's modulus, the modulus of elasticity, divided by the specific gravity—we get practically the same figure, the ratio varying only from 3.7 for magnesium, 3.8 for steel and wood, and 3.9 for aluminum to 4.0 for silica and common glass. This very interesting result affects profoundly any possibility of some new way of using existing materials as, for example, by a wide extension of aluminum and its alloys in view of their light weight. There are economic considerations that will naturally affect any such developments, especially if recently reported possible simplification of the manufacturing process for aluminum is achieved on plant scale, but this significant similarity of the specific strength of materials already in use—and that is to say, materials most commonly available—puts an insoluble bar in the way of any "breakthrough" in their use for ordinary building processes. A great deal of work is naturally being done, in all parts of the world, in the search for new materials that will solve some of the problems in material supply. There seems to be little possibility that the one important metal that does have a lower specific weight, beryllium, will ever come into widespread use even in small quantities if only because it has the unfortunate property of being poisonous. There appear to be great promises of real advance in whisker technology (as it is called) but even the most optimistic forecasts do not even contemplate the use of such artificially compounded materials being used in building work.

Even if I am wrong in this assessment of the current material situation—and I could well be too conservative in my approach—the problem of the supply of necessary materials for the remainder of this century would still not be solved. There never has been any sudden "breakthrough" in the steady advance of building through the ages so that it is quite impossible to contemplate any sudden and drastic change in building technology in the two decades immediately ahead, the period with which we are more particularly concerned today. Consider, as but one example, the case of structural steel, one of the most versatile and remarkable of modern materials, without an adequate supply of which the building of modern Canada could not continue. Study of the records of construction in the last century show clearly that, from the time when structural steel was first commercially available to the earliest time at which it could be said to be generally accepted for common use, at least 25 years elapsed, and more probably something like 35 years. This was due not to any opposition to steel from established materials, nor to undue conservatism on the part of designers, but to the inevitable process by which a new material may safely be integrated into uses upon which human lives depend. That situation has not changed today so we can be quite certain that there will be no revolutionary changes in the character of material demand in the years immediately ahead, even though the quantities demanded will continue to mount, limited though the supplies may be in the long term. The future of mining, in its broadest sense, is assured but so also are the challenges that will face those responsible for it in the relatively few years that remain before the twentieth century becomes the twenty first.

On that day some of the young men and women who are about to begin their university studies today, will be approaching the peak of their professional development, the younger amongst them facing the new century with the eternal optimism of youth. They will all be able to look back to this day just as we can today, so easily, to the years immediately following the end of the second world war. What will they think of our planning, of our recognition of what their needs will then be, of the assistance that we were giving as a most favoured nation to the under-developed parts of the world, above all of our appreciation—or the lack of it—of the underlying cause of all the concerns that I have so far shared with you? All of you know well that at the root of all problems of expansion lies the population explosion that has been going on throughout the world ever since the end of the second world war. We all know this instinctively, but I wonder if we appreciate as fully as we should how very serious the situation is. Let me try to put it before you in the bluntest possible terms.

In the year 1750 the total population of the world was about 700 million, this being the first reasonably accurate estimate that we have available. By the turn into this century the total had doubled, being 1.6 billion in 1900. By 1965, less than half the period required for the first doubling, the population of the world had doubled again, now amounting to 3.3 billion. In six more years it had risen by another 400 million and the increasing rate of the increase continues. It might be helpful if I indicated what these figures mean by saying that in the short span of time during which I have the privilege of addressing you the net population of the world will have increased by well over 5000 souls. The inevitable result will be, if no world catastrophe takes place, that by the year 2000 the population of the world will be almost double what it is today, certainly more than double what it was in 1965. And the cities of the world, whether we like to contemplate such a prospect or not, will be far more than double in size and area than they are today. Not only is there the increase in population to accommodate but in every land there is a drift to the cities that apparently cannot be stopped and, as all who have travelled know well, there are all too many cities in the world which cry out for improvement and enlargement in order to provide a mere minimum of decent living for their inhabitants.

This prospect is so serious in its implications and so disturbing in its magnitude that it is all too easy to take the view that, even if true, it is so far removed from the affairs of today and tomorrow that it can be regarded with merely academic interest. I would be derelict in the duty that is mine today if I did not urge upon you, with all the emphasis at my command, that this is something that is entirely relevant to the dedication of these new facilities at this University. The facts about the population explosion are not mere fantasy; they can be checked in successive issues of the *Demographic Year Book* of the United Nations where one can see that the revisions and refinements that are made from time to time are always revisions upwards. The corresponding figures for Canada are to be found in the *Canada Year Book;* the increase is not quite so spectacular and disturbing but the population of this country has doubled since about 1941 and the recent rate of increase has itself been increasing. And with a doubling of population, what possible conclusion can one draw about physical facilities other than that they must also be doubled at least, if even minimum accommodation is to be provided for the seven billion inhabitants of this planet in the year 2000? It is for this that materials will be needed in such gargantuan quantities. It is this prospect that makes the future of mining so full of challenge, and questions.

There are some who suggest that shortage of food on a world scale will act as a brake on population increase; others question this. Control of population, however, must somehow be achieved directly rather than by relying on starvation to do the job for us. The Japanese have shown the world what can be done but their example is still almost alone. Those of us who have had the high privilege of visiting India and talking with her leading citizens know well how disturbed they are at the terribly slow progress that they are making in birth control, despite all the efforts and money that have already been devoted to this national effort. The well documented experience in the Ludhiana district of the Punjab shows clearly some of the difficulties. It is a strange commentary on the times in which we live to find that, despite world-wide concern about population control, the Government of Canada supported by parties in opposition has just passed legislation increasing family allowances, a direct incentive to larger rather than smaller families.

"There are three imperatives" Sir Ian Macfarlane Burnett has reminded us "to reduce war to a minimum; to stabilize human population; and to prevent the progressive destruction of the earth's irreplaceable resources." All three are inter-related. Today we are concerned primarily with resources. Mineral resources must be used to serve the world's needs, but not blindly. They must be used in full realization of the fact that they are non-renewable and that in the winning of them the surface of the land must not be despoiled. These are the challenges of the future that must under-gird the training of young minds, so that when they come to the year 2000 they will be able to look ahead with confidence and look back without dismay, knowing that their problems were recognized as our problems.

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Mining in the Next Decade

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To use terminology that is in popular use, the "time frame" for today's symposium on trends in the mineral industry is the next decade. Ten years always seems a short period when one looks back in time, but is disconcertingly long when one undertakes to comment on how one's industry will develop. I am conscious that many of you in your managerial or professional capacities are participating in long-term planning, long-term projections which are important to you and to your company. And you are accustomed to seeking out and identifying the factors which will be significant in the longer term. To achieve this perspective one must not over-emphasize, or be diverted by, those events that draw public and industry attention for a relatively short time and then fade in significance or prove to be only part of a more significant trend. Although our time frame for today's symposium is ten years, I shall comment briefly on the attention that has recently been focused on a much different time frame by the popular report of the Club of Rome on the predicament of mankind posed by exponential growth in population, food and energy consumption, minerals consumption and pollution. This report, which attempts to consider the inter-relationship and consequences of many factors as they are subjected to exponential growth, is symptomatic of the developing public concern with growth and quality of life. The report has met with great acclaim for the attention which it focuses on the consequences of growth that is uncontrolled or controlled too late. At the same time, it has generated criticism from many quarters on the basis that some of the assumptions are inadequate and that the projected dismal consequences 100 years hence are avoidable. Spokesmen for the mining industry, while recognizing that minerals reserves are finite, do not subscribe to the proposition that non-renewable natural resources will become inadequate for the world's population over the next century or less. I do not intend to digress into this time frame or to make any detailed counter-comment. Suffice it to say at this time that, to meet natural resources requirements, we look to improved technology, substitution trends, rising metal prices and lower grade deposits, the vast potential of minerals lying on our ocean floor and the capacity of the market system to stretch supply through orderly price increase. All of these are factors that cannot be quantified. This does not imply that continuance of wasteful consumption can be tolerated. We must foster wise and careful use of our resources to a degree not contemplated in the past. Scrap recovery, including garbage, recycling, a changing philosophy and attitude towards planned obsolescence and conspicuous consumption will play vital roles in our mineral economy. Consumer expectations will have to change, as is most forcibly shown by the current public concern in the U.S. about fuel and energy shortages predicted for this winter.

Canada's Position as a Mineral Producer

Let us look briefly at Canada's present position as a mineral-producing nation. I do not intend to retreat into statistical tables, but I think it desirable to summarize certain economic highlights as a background for a glimpse into the future.

Canada's Gross National Product last year—for the first time—surpassed $100 billion, partly owing to a 7 per cent increase in mineral exports over 1971 levels. The mineral industry achieved new production levels, too, with total value of output reaching $6.4 billion. Investment was at a high level ($1.7 billion in 1971 in the mining, smelting and non ferrous refining section as compared with approximately $20 billion in all Canadian industrial activity for that year). These results reflect a healthy, vigorous mineral industry that is a major contributor to Canada's economy. As Canadians, and in particular as Canadian mining people, we are proud, and justifiably so, of the industry's contribution to the nation and of its increasingly progressive approach to maintaining and advancing its competitive strength in world markets.

An awareness of future trends, economic and technological, is essential to the decision-making of this decade, and today I shall comment on some of the factors which will be of particular significance in moulding events for our industry. One cannot look into the future in any practical way without sober reflection on the accomplishments of recent years, the factors influencing change, the current rate of change and the momentum carrying us into the next ten years. I have no desire to slip into the science fiction that becomes tempting if one looks far into the future, or if one conveniently disregards the realities of our industrial base. Already our technological reach may well exceed our practical grasp. We must not underestimate the time factor needed to reach some of our goals.

With this in mind let us reflect on what we have achieved in the last ten years or so; possibly we will find that our grasp, in some instances, actually exceeded what we had thought possible. I will mention some of the highlights of industry trends for the period and I am sure that this will stimulate each of you to recall others. Possibly you would place emphasis on other highlights. In fact, my initial list was so long that I abbreviated it because our real interest is in the direction and implications of future change. Here are some highlights, but not given in any order of relative importance:

1. The rapid, widespread adoption of computer techniques in all phases of mining from evaluation to mine planning, from process control to data control;
2. The remarkable size and daily tonnages of so many new mining complexes;
3. The low-grade mineral deposits now being mined that in the 1950s and early 1960s would have been considered marginal or even uneconomic;
4. The great size and technical sophistication of new mining

equipment, especially in surface mining; the rapid acceptance of large mobile excavation, hauling and drilling units in underground mines;

5. The fast-growing emphasis on environmental protection—air and water quality, tailings disposal requirements, reclamation planning; "Ecology, ecologists, conservationists"—all are now familiar terms in our industry;
6. The growth of Western Canadian coal in importance; and
7. The energy "crunch".

We cannot, of course, limit our thinking to technological changes. One can enumerate many other factors which greatly influenced our industry in recent years. For example: the rapid rate of social change; the new work ethic; taxation and government regulations, including the loss of incentives and new restrictions for mining and mineral exploration; changing trade patterns.

In retrospect, too, one must be impressed by the rapid rate of growth of capital expenditure in the mining industry in recent years. Basically, this was caused by two factors:

1. The changing commodity composition of mineral products; and
2. The advances required to achieve greater labour productivity in the face of competitive world market conditions.

The increasing capital intensity in the mining industry and the relatively low incremental demand for labour are factors of increasing social and economic impact—as the expectations and values of our population undergo rapid change.

To sum up, I think you will agree that, although the changes seemed gradual to us as we experienced them, the cumulative changes and effects over the last ten years are quite staggering. And the rate of change has not slackened; indeed, it is accelerating. The main factor in sustaining the world's economic reserves has been improved technology. There now are many instances of massive low-grade deposits becoming economic as a result of handling vast daily tonnages of ore with giant open-pit equipment. We must expect that the rate of minerals consumption, coupled with international political events, will result in prices and substitution of resources playing much larger roles in sustaining economic reserves of minerals.

Mining's Public Image

I should have liked to include mining's new public image as a principal highlight of recent years. That I did not list it under that heading is not an oversight. I do think the industry is making real efforts to improve its image and to be more responsive to public opinion than in previous years; most certainly there has been increasingly favourable public awareness of mining. We still have to work at that image with convincing evidence that it is deserved. It is fair to say that most of us are convinced of the need to project an image that accurately portrays our efforts and our desires to operate responsibly, as well as efficiently, in the public interest as well as in our own economic interest.

Although we have in the past neglected to inform the public adequately, we are a very visible industry in the physical sense; evidence of our past operations is bleakly evident in too many places. Although mining occupies only 150,000 acres out of a total of 2.3 billion acres, it is unlikely that even in remote locations we, or others, can have the disregard for the environment that was commonplace in earlier days. Design of new mining complexes, large and small, already must meet stringent new considerations for environmental and social impact. With greater awareness and recognition of the need we will see great changes from now on—new surface plants often will be well screened by trees and landscaping, and future operations, I believe, should be below ground where possible. This could include hoisting, crushing and milling facilities, possibly even preliminary concentrating operations. Increased disposal of tailings in mined-out stopes is a possible measure.

The Work Force

The miner, with his pick and shovel and pneumatic drill, the mining town, often with its unattractive, temporary appearance and boom-and-bust memories, the grey waste piles and scarred landscapes of coal regions still linger as part of the image of mining conjured in the public mind. Hopefully, this image is associated now only with the past. The need to make mining attractive enough as an industry to compete with alternative employment will become increasingly evident and necessary. The offer of high wages even now is not enough to attract and retain a stable labor force in mining areas that are at all remote from other towns. The development and improvement of communities with housing, recreation, education and communication facilities at least equal to, or better than, those in industrial areas, will play a much larger role in the economics and decisions of mining development, much larger even than we can envisage from 1973 experience. Of course, there are numerous examples now of model communities serving mining complexes in remote and semi-remote regions; but new communities of the seventies and eighties will not necessarily follow this pattern however excellent it may have been for the sixties. Community design may undergo very basic changes. Transportation and communication facilities and government services for the population of the new communities will play a much larger role in the decisions on controlled community design and location.

Commuting of the labour force by air from an established town, or from a community designed to serve a large area rather than one or two mines, will not be uncommon. In fact, a new uranium mine in northern Saskatchewan by 1975 will be flying its personnel regularly to its remote mine site from Prince Albert or other communities and returning them to their families in those communities several days later. Certainly we will see in the next decade the controlled siting of new communities designed to be permanent centres for the development of the resources of new regions and for extending a planned pattern of transportation and communication services.

Our work forces will be drawn from a population of young people who are better educated, more travelled and more questioning of the social order and the work ethic than any previous generation. They are insulated to a great degree against the need to take any immediate employment just to survive and eat regularly. And there will be a far wider range of attractive career opportunities in fields that previously did not exist at all. Computer science, electronics, television and space industries did not exist as career options for many of us in our youth. The attractiveness of these industries now provides for many young men the opportunities and excitement which used to be associated with mines and minerals in distant places. The mining industry will have to compete for its work force in a population which increasingly prefers urban life, demands urban standards and requires more from employment than a regular pay cheque and security.

The pressure of industrial unions to force re-thinking and re-design of assembly line operations is, in my view, only the beginning of a new emphasis on the "humanizing factor" in work activities, an emphasis which will have major effects on working conditions in industry in the next ten years. This will apply at all job levels. By "humanizing" I mean the inclusion of more autonomy, responsibility and variety in work activities. In the mining industry it will mean more advanced mechanization and automation in which operator comfort and work satisfaction will play a larger part. A recent cover page of *The Northern Miner* illustrated this point very strikingly in a photograph of the operator's cabin of a new Swedish drifting and tunnelling rig which is sound- and vibration-insulated and has, among other features, instrumentation, filtered ventilation, cabin heating and lighting, all designed to make the work safer, easier, more comfortable and more productive—and this is not an isolated instance. All operator-manned equipment, from heavy open-pit trucks to controls for process machinery, must be designed with greater "human engineering" content if we are to attract and keep young people in our work force.

Research and Development

Canada can make a real contribution to orderly development in meeting the enormous future demand for the world's minerals. Measures already have been initiated by the Federal Government to encourage the participation of industry in setting Canadian goals, in decision-making and in the shaping of effective courses of action for research and development through National Advisory Committees. This, in turn, is matched by the determination of the mining industry to secure effective action and to enhance relations with all levels of government.

Many of you are aware that a national body was established several years ago to advise the Canadian Government on mining and metallurgical research. One of its chief tasks is to identify those avenues which will lead to significant advances in technology for the industry. The wide scope of the proposed projects will be of interest to you. They are:

1. Primary Excavation Method in Underground Metal Mines;
2. Steep Incline Conveying for Ore Haulage Systems;
3. Application of Hydraulic Hoisting and Ore Transport in the Mining Industry;
4. Development of High Capacity Method for Mining Deep Sea Nodules;
5. Development of *In-Situ* Method of Recovering Synthetic Crude Oil from Athabaska Tar Sands;
6. Improvement of the Mining Working Environment;
7. Strata Control in Potash Mines;
8. Ground Support Systems.

I think this will indicate to you that your industry is not sitting back, making predictions about the future and then awaiting positive actions from others. The first step in making progress is to identify projects on which research should be concentrated. The sub-committee, of course, is recommending courses of action to be taken, together with schedules for the application of effort and funds.

Rock Breaking

Rock breaking, from time immemorial, has been the very basis of the mining industry. Rock excavation has not radically changed in the past ten years. Certainly there have been real improvements in drilling equipment, in explosives and in excavation techniques. One is aware of the tremendous desire and interest, unsatisfied so far, to break through to radically new rock excavation concepts. The time is indeed ripe for change, and industry is ready to accept and support a rapid development of new excavation methods.

Our present rock breaking science is sound and steadily improving, but it has many primitive aspects. Most excavation must be done by drilling numerous holes for the controlled distribution of explosives in a rock mass. We have progressed a long way from the early days of mining when drill holes were the result of human muscle and heavy bar-mounted pneumatic drills. But the principle has not changed—we still are drilling and blasting rock in enormous quantities daily around the world. Fortunately, the equipment often is highly sophisticated, highly productive and heavy manual effort in rock drilling is decreasing rapidly as power assists become more common. Explosives certainly have improved. The range of types for special purposes is good; our understanding of them and their action in rock breaking undoubtedly has increased very substantially. Rock breaking with explosives, although still an art in its application to individual mining situations, has been subjected to very thorough scientific scrutiny in recent years. We will continue to see substantial improvements in the art and science of drilling and blasting over the next ten years, probably mostly concentrated on the sophisticated control of these operations and in higher labour productivity; but there is no real prospect that our present methods will be superseded to any significant extent in the next ten years by radically new methods of breaking rock.

Some developments we *will* see are:
—an increasing use of slurries, on

surface and underground, largely displacing nitroglycerin based explosives. This will be accompanied by wide use of pneumatic cartridge loaders in underground mines. Mechanization of the loading of explosives will take us out of the "model-T" era of hand loading, which has been practised for so many years.
—"tailoring" of explosives using computer design. This may be based on energy requirements as measured and analyzed during the drilling of rock in production areas. Already the familiar "powder factor" is obsolescent; "energy density" is a concept that will guide us in the design and control of rock blasting. In short, blasting will become more scientific in its application as we develop proficiency in analyzing rock factors.
—an increasing cost for explosives caused by rising cost of materials; for example, the demand for ammonium nitrate for fertilizer has a direct bearing on its cost to explosives manufacturers, and currently fertilizer demand is the highest in years.
—wider use of larger diameter drill holes underground and a move away from the perforation of working faces with numerous small holes; it is quite likely also that electric drive for rock drilling rigs will become accepted in more applications.

Looking further into the future, I do think that rock breaking progress eventually will make great strides. Perhaps our present methods will look quite antiquated to mining engineers 15 years in the future—but it may be 20 years before this happens. Those of you who are close to actual developments may feel that change is nearer than that. We need a few more years before any really rational assessment of the potential of non-conventional techniques can be made. Each year brings its share of press reports about a new development that may revolutionize rock excavation methods; but progress generally has not been dramatic, in spite of the genuine interest in early development of new techniques. There are exceptions; for example, rock boring, particularly for raise excavation, has made much progress in recent years in hard rock mines. Tunnel borers, too, have demonstrated their commercial practicality for specialized tasks. I think we will see rock borers gradually increase their acceptance as specialized excavators; I am doubtful of their acceptance for hard rock production applications, except for limited applications, in the foreseeable future. Let us look briefly at some of the non-conventional primary methods of rock excavation which hold promise for the future:
—hydraulic jet underground coal mining. Techniques already are well advanced in Western Canada and it is quite likely that this method will gain increased acceptance in the next few years.
—water jetting for tunnelling with pulsed jets from a "water cannon" to shatter rock at pressures from 300,000 to almost 1,000,000 lbs. per square inch.
—*in situ* leaching of low grade ore preceded by fracture of the deposit with explosives or by use of hydraulic fracturing techniques.
—the electron gun, which melts cuts in rock, is intriguing because of low power costs and no moving parts. Whether it can be successfully applied to production or to rock tunnelling remains to be demonstrated.
—hydraulic impulse breakers are being investigated by several companies.

With the exception of hydraulic coal mining, the outlook for a breakthrough with one of the exotic, unconventional approaches in the next few years is not particularly encouraging. The prospect is for quite a few more years of development effort followed by limited use in specialized applications.

Mining Equipment

Time does not permit any detailed comment on the probable evolution of various types of mining equipment over the next decade, but I would like to express some thoughts on general trends. First, in any discussion of equipment we should make a distinction between open pit mining and underground mining applications.

Open pit mining has been striding along in "seven-league boots" in recent years and the emphasis has been on size of equipment. Each year we have been impressed by announcements of bigger machines and plans by manufacturers to design even larger units. Underground mining has not made comparable strides because of the physical constraints on equipment size and manoeuverability inherent in underground operations. That is not to say that underground equipment innovation and application has lagged; it is simply that the goals of productivity and cost reduction must be achieved in a different physical environment. Let us consider surface mining first. At least two-thirds, possibly more, of the world's mineral requirements are being produced by open pit mining methods. The keys to this predominance are the phenomenal improvement in productivity and low operating costs per unit of production made possible by giant machines which can excavate and transport very large tonnages of rock and overburden. The spectacular size of some mining equipment gets the headlines, creates wonderment at the rapid changes in sizes and models and probably also creates an inaccurate picture of the present equipment situation. True, haulage trucks in the 100 to 200 ton load capacity range are available and in operation, and even larger units probably will appear. One must recognize, of course, that these mammoth units find application only in a few very large operations; most haulage trucks being sold now and over the next decade will be of lesser size than the giants simply because equipment has to be properly sized for each mine, and suitably matched to the capacities of equipment performing other tasks in the production cycle. The emphasis now should be on improvement of *components* of the equipment that has been developed so rapidly. Big machines with huge loads must meet service conditions that impose extremely severe demands on tires and engines. It is not unreasonable to demand, and expect, really significant improvements in both in the next few years as advances are consolidated and equipment is modified as the result of operating experience. There will be much increased emphasis on improved availability, and operators will stress the need for reduction of operating and maintenance costs of components. This should lead to very significant advances in the design of heavy equipment *components* in the decade; indeed, it would be unfortunate if proliferation of equipment in very large sizes continues at the same rate as in the past few years, too much in advance of adequate field testing. In short, the mine operator now has a very wide range of choice in basic open pit mining equipment; power shovels, front loaders, dozers, scrapers and haulage trucks are available in a myriad of sizes and sophisticated models. The stage has been set well for the design improvements that will make them more efficient and more satisfactory machines in the next decade.

Underground mining imposes such severe and special conditions on equipment design, particularly for trackless operations, that the advances in equipment are not as spectacular as in surface mining. A characteristic of surface mining that often creates the need for big equipment is the large tonnages of waste rock and overburden that must be excavated and hauled. Underground operations, on the other hand, must be very selective and machine designs and capabilities must be tailored or specially adapted to the limitations imposed by the existing mine lay-out and the deposit. In fact, the evolution of machines of advanced design sufficiently rugged to operate efficiently underground in hard rock has been quite remarkable in recent years. Introduction of trackless equipment often requires substantial modification of the mining method—or again, the versatility and productivity of the machines may make possible major redesign or major improvement of the mining method. In any case, the evolution and adaptation of the advanced equipment must proceed quite deliberately, and the changeover time is measured in years rather than months. The outlook is for an increasing sophistication in underground equipment, more power assists in machine operation, and more instrumentation. Significant productivity improvements can be expected as higher standards of mechanical ruggedness and component life develop. Environmental requirements for noise, dust, air quality and mine safety measures will play steadily increasing roles in machine design and operation.

Undersea Mining

The recovery of commercial mineral resources from the ocean floor has intrigued mining companies in recent years and few will doubt that practical operations will become a reality. Scientific curiosity, supported by the undertaking of underwater mining research projects by a number of U.S. and foreign groups, is resulting in a body of knowledge, particularly as to manganese nodule mining sites. Recovering nodule material from ocean depths of 10,000 to 15,000 feet poses problems entirely new to the industry. I cannot comment on which of the possible lifting systems are likely to dominate. Those most frequently mentioned are the continuous line bucket, vacuum cleaner-hydraulic, and hydraulic. Quite recently it was disclosed that the Ocean Mining Division of Hughes Tool Company is preparing a large vessel of special design costing perhaps $35 to $40 million, which will be fitted with secret mechanical and electronic gear. This vessel, 618 feet in length, will be supplemented by a strange secret barge which is said to be submersible to service the mining system. How this equipment will be used is not known but it surely will be an important step in the progress of ocean mining toward commercial realization. In fact, I understand that this mysterious vessel now has taken a position at sea near Hawaii, presumably for commencement of operations. The exploitation of undersea mineral resources in international waters now poses new problems and questions as to control of activities, and as to the effects of large scale exploitation of the economies of some nations who rely largely on the production of the same minerals. The significance of developments in undersea mining and the related international effects of successful exploitation will become apparent during the next few years and we will hear a lot about it from now on, as public awareness grows. We should not underestimate the significance of possible developments, the early results of which are not as far in the future as one might imagine. Indeed, I think it correct to describe the present stage as being on the edge of a new frontier of mineral recovery from a watery environment entirely new to our industry.

Exploration

Previous governments of Canada encouraged the development of mineral resources through two main incentives; the three-year tax exemption for new mines and a depletion allowance for replacement of a wasting asset. These policies, tested by time and experience, recognized the special characteristics and risks associated with the mineral industry in an era when Canada was becoming more and more isolated in a world of massive trading blocs. The success of the great level of exploration over the past 25 years, based on favourable geology, was fostered by an internationally competitive tax structure in a stable political climate. There was world recognition and admiration of Canadian mineral policy.

The Royal Commission on Taxation of 1967 recommended profound and radical changes in the tax structure for mining. Since then the industry has lived through four years of uncertainty followed by tax legislation much less favourable than that previously existing although better than that recommended by the Royal Commission. This has had a very depressing effect on the search for minerals in Canada.

Exploration is an expensive, difficult and extremely risky venture. After the discovery of an orebody, vast capital expenditures are required over the protracted period between discovery and production of minerals. It has been estimated that $40 million, on the average, is spent before a productive orebody is found. To keep mining attractive to venture capital, there must be rewards to investors commensurate with the high risk of exploration and mine development.

The future tax climate in Canada, together with the inhospitable trend toward less foreign ownership, has created apprehension in sources of capital. With the exception of the harsh and arbitrary measures taken over uranium, which has extinguished uranium exploration in this country, no positive action yet has been taken to stop development of new mines in Canada by foreign capital; but the emotional debates over the issue definitely have reduced foreign capital inflow for new mines in Canada. The net effect has been the diversion of capital to the basic resource industries of other countries, with negative results to the Canadian economy.

Summation

In summary, I believe that the future demand on our mineral industry can be met by a four-tiered attack:
1. More intensive exploration;
2. Mining lower grade ore deposits;
3. More research in mineral recovery methods and in mining methods;
4. More investment for mechanization.

The long-term outlook is obscured by cost inflation, a confused tax system, a precarious international situation, and uncertainties about government policies and attitudes affecting the mining industry.

Nationalism is on the rise in Canada and elsewhere throughout the world, with increasing effects on international metal markets. The lack of economic stability and political integrity in some countries should present opportunities for our governments to establish Canada firmly as the world's most stable, and leading, supplier of metals and minerals. This will require consistent policies toward the mining industry to create the atmosphere for the capital injection needed for a great potential surge in production. In the absence of a large domestic market, but with the resources capability for great mineral production, Canada amply can supply its own needs and continue to be one of the world's leading suppliers in a wide range of mineral commodities.

A comprehensive national mineral policy is needed to support our domestic mineral consumption and Canada's position in international trade. To achieve this, we must establish well defined long-term guidelines—a framework into which our future mining development can be fitted. Overall objectives should be based on the premise that the future balanced growth of our Canadian economy and the well-being of Canadians depend to a significant degree on the ability of this country to develop its natural resources in an orderly manner—with particular emphasis on minerals.

This mineral policy should be integrated into a national industrial policy. Particular attention must be given to the creation of employment, our relationships with the United States and protection of our environment. The industry believes it is very short-sighted and unwise for any Canadian government to determine national industrial policy with exclusive emphasis on labour-intensive segments and without giving serious regard to the very important influence of the resource industries in creating industrial employment. Fortunately, the proposed federal tax changes are being introduced over a number of years and hopefully there will be revision before the full negative impact of tax legislation is felt.

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Mineral Processing in the Next Decade

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I am fortunate to have my prognostications on mineral processing limited to ten years. Over that short span one can assume that any important process metallurgical development likely to see the light of commercial application will be well along in the laboratories of the industry as well as in the patent offices of the world.

Process metallurgy, in common with many other industrial activities, is beginning to feel increasingly the restraints consequent upon such factors as the developing shortage of energy supplies, the quality of the physical environment and the certain prospect of leaner, more complex ores to satisfy the hunger for metals of an expanding population eager to improve its quality of life.

Overshadowing all other concerns is that of energy. The outlook based on fossil fuel and even fission is discouraging. The long-term hope depends on the development of new sources of energy, be it solar, aeolian or fission. But before their advent it will be necessary to develop fully the existing sources. Possible environmental dangers must be overcome before they interfere, and this by the application of our technology and our ingenuity. Not the least of these concerns, as energy consumption increases, is the disposal of residual low-grade energy which is already beginning to cause minor embarrassments.

In the realm of the physical environment, emotionalism is giving way to cool assessment which, in the metallurgical industry, will provide a better atmosphere and an opportunity for planning. In the metallurgical world the physical quality of the environment need not be placed in jeopardy by increasing activity. Technology has progressed to the point where non-polluting plants can be built. Henceforth, capital cost of any new project will include that required for environmental safeguards. Should the project prove to be economically unattractive under these circumstances it would not be undertaken, except in rare cases and for the greater public good.

The environmental problems of the metallurgical industry lie not in the future but in the past. It is the revision of older plants which presents serious problems. But even here, significant progress is being made.

In metallurgy, particularly in non ferrous metallurgy, the most significant development took place near the turn of the century, following the invention in Australia of froth flotation. The world's gross demands for metals would not have been met without this tool which has turned common dirt into valuable ore. In the light of our dwindling reserves, one can only dream of a comparable development. I do not see this as a reality in the next decade. Something of promise seems to be on the horizon in the form of super-magnetism now being developed for large scale industrial application. Early trials on minerals separation have not confirmed the optimistic outlook, but we have observed only the very beginning and there is reason for optimism.

In the field of ore processing, beneficiation will continue to make progress, albeit along conventional lines as the discipline applies itself to the task of increasing metals recovery from leaner ores and of sharpening the separation of mineral species. Unfortunately, because of the energy constraints there also will be a call for higher grade concentrates, a call hardly compatible with the other requirements. There is also the necessity to preserve the environment which involves among other things, practically total water recycle, treatment of effluents, and soil restoration. However, given the economies of scale, the new highly automated facilities, together with the more selective and reliable instruments for on-stream analysis, such progress is to be expected.

The long range outlook for metals is much more promising than for many other sectors of the economy. Like you, I have scanned the projections of limited reserves of ores. In some instances, such as for the ores of tin, reserves are so low as to encourage an immediate search for substitutes. However, most base metals, those ranging in stability from aluminum down to copper, after having been mined, processed and used, need not be and usually are not lost. Would you believe, for example, that 85 per cent of all the copper ever mined is still in use, that even now some 35 per cent of the nickel of commerce derives from recycle, that much of the steel in use can be recovered given a satisfactory price structure.

It is sometimes proposed that ores be left in place for future generations rather than have them exploited for unessential uses. In the light of what we have seen, I disagree. I think it preferable to mine and process such ores and to utilize the metals for whatever need. This places them in a utilitarian reserve on surface, largely processed and available for more important uses should the need arise. Indeed, I place most metals in the category of renewable resources—more renewable even than trees because they do not require replanting. They remain available in harvested form.

The reality of this situation will become more apparent in this decade as research develops procedures for more effective use of scrap materials.

The situation with respect to non ferrous metal ores is lightened by the fact that geological exploration, despite the availability of rather sophisticated instruments, has to date successfully penetrated only to a depth of some 300 feet, or hardly scratched the surface. The advent of more selective and more penetrating instruments in the future may reveal additional bodies. However, these would have to bear a higher cost for exploration and production.

The outlook for non ferrous metals reserves received a boost in the last• decade from the discovery of the undersea manganese nodules. These are roughly 2 in. diameter balls containing about: Mn, 25%; Ni, 1%; Cu, 0.5%; Co, 0.1%. The mechanism of their formation is not understood. All of the metals occur in a relatively high state of oxidation in an environment of low oxidation potential. The nodule reserves are estimated in the billions of tons. Speculation has it that the metals are being deposited at a rate which exceeds current consumption. The nodules occur as a unilayer spread over wide stretches of the central Pacific at depths of about 18,000 feet. Extensive, though lower grade nodules are also known to occur at a depth of 5,000 feet on the Blake Plateau in the Atlantic off the coast of North Carolina. I spend time in dealing with these deposits because they represent such a huge reserve of key metals. Their formation constitutes nature's way of recovering the metals from extremely dilute solution. Man's technology is not yet equal to such a task.

The harvesting of the nodules by the methods under development would not seem to have harmful environmental consequences.

Ferrous Metallurgy

In ferrous metallurgy, iron ore supply is not seen as a problem in the foreseeable future. Consequently, research will be directed to upgrading the raw material.

The blast furnace will continue to dominate the scene with emphasis on increasing size and decreasing coke consumption. Direct reduction, electric furnace smelting will gain acceptance, particularly for smaller installations in more isolated areas. Nevertheless, the tendency will be to continue to build high productivity, fully integrated steel works.

Refining of blast furnace iron into steel has moved massively in the last two decades towards the use of oxygen. The B.O.F. now accounts for fully 50 per cent of total world steel production. The trend will continue through this decade, but probably at a slower rate.

A similar move has taken place in alloy steel production. Here, the recent development of the Argon-Oxygen process and furnace has heralded an exciting new era. The new technique of bottom or side oxygen blowing through tuyeres cooled by argon or, in some instances, by natural gas, provide the high degree of turbulence required to attain chemical equilibrium and ready control over the operation. In stainless steel production, it is providing high chromium recovery heretofore unattainable. It is permitting the use of less refined additives becase of the ease of removal of impurities. This has had an effect on such materials as nickel since the process will accept less refined grades such as the ferro-nickels produced from laterites and the oxide sinters available from Canada.

Non Ferrous Metallurgy

In the realm of non ferrous metallurgy, I can deal only in general terms rather than with specific metals. I shall also direct my remarks mainly to the sulphides since they will continue to dominate the Canadian scene in the next decade. Processing of sea nodules, which are oxidic, will probably not become an important undertaking in the period under consideration. In any event, conventional processes are applicable to their treatment. The problems which first must be resolved are those of harvesting.

In the field of base metal sulphides, the major processing problems stem from the presence of sulphides of iron. In some cases, these far outweigh the sulphides of the value metals. Currently, two procedures, hydro-metallurgy and pyro-metallurgy, are competing for the treatment of the bulk of the sulphide concentrates. Vapo-metallurgy, which we think is a godsend, has application only to a limited number of metals. Hydro-metallurgy teaches that for new installations wherein sulphur dioxide generation is to be avoided, procedures are available for further development. Some processes involve ammoniacal leaching of concentrates at atmospheric or super atmospheric pressures to form water-soluble amines of the value metals and ammonium sulphate which can be sold if conditions warrant or, alternatively, can be treated for the recovery of ammonia for recycle and for the formation of gypsum as a sink for sulphur. Other processes involve oxidation with oxygen under pressure and under slightly acidic conditions to form sulphates of the value metals, to discard iron mainly as basic ferric sulphate and to recover the bulk of the sulphur in its elemental state for sale or storage. Such sulphur is generally contaminated with small quantities of selenium which detracts from its sales potential. Various schemes such as precipitation – electrowinning or hydrogen reduction are available for metals recovery from the purified solutions.

On the other side, pyro-metallurgy continues to present a valuable technique from the standpoint of energy utilization and for treatment of lower grade materials in large tonnage at reasonable cost.

Non ferrous pyro-metallurgy is turning progressively to the use of oxygen to thereby eliminate what my colleague and pioneer in this area, Paul Queneau, calls "the dead hand of nitrogen". The consequences of eliminating some 80 per cent of the gas burden need no elaboration. However, pyro-metallurgy, regardless of the means by which it is conducted, inevitably involves the generation of sulphur dioxide. Two control methods are available and may be used jointly. The one involves the removal for separate treatment or stockpile of the cleanest possible iron sulphide concentrate to leave a value metals concentrate with the lowest possible sulphur content. The other involves smelting under circumstances which will produce either a high strength gas for liquid SO_2 or a gas of 5 to 10 per cent strength for sulphuric acid production. The use of oxygen flash smelting or the newer T.B.R.C. system favours liquid SO_2. Fluid bed roasting followed by electric smelting favours the sulphuric acid path. In each instance, the problems related to lack of markets and to shipping costs of these products are strong negative factors. On the other hand, can you imagine how nice it would be to produce acid from liquid SO_2? A possible alternative is reduction of SO_2 to elemental sulphur but the energy balance of the total system then becomes decidedly negative and the economies of the process are unfavourable, particularly in the face of increasing natural gas prices.

I can see no major process changes in the metallurgy of the oxide ores of base metals, particularly those of aluminum, chromium, tin and nickel. For nickel, large reserves are present in the tropical and sub-tropical areas of the world. Exploitation of these is becoming an important factor in the industry. The ores are esentially sulphur-free and problems from SO_2 emission are minimal. The ores are not amenable to major concentration by conventional means, making it necessary to treat practically the total ore for recovery of the value metals. Applicable processes vary with the type of ore. Generally, the silicate ores lend themselves to reduction smelting to ferro-nickel or matte, while the limonitic ores respond to selective reduction at high temperature followed by leaching in ammoniacal or acid media. A vapo-metallurgical carbonyl process has also been developed for the extraction of nickel from selectively reduced limonitic ore. The leaching of raw, wet limonitic ore under pressure in a slightly acid medium went on stream at Moa Bay, Cuba in 1960. Its performance has been variously reported as being excellent or poor.

In summary:

1. I see the key metals as renewable resources and their continued availability not a serious cause for concern,
2. In the next ten years, the metallurgical industry will demonstrate its ability to design and build plants which will operate in harmony with the environment.
3. I have concern over the availability of energy resources for the long term—not for the coming decade.
4. Progress in process metallurgy may not be spectacular over the next decade but I think it will be real.

Finally, the need to return to the laboratory is paramount if we are to avoid being lulled into a false sense of achievement by our own propaganda. For here is the cradle of material progress. The example was set by those whom we honor today and in whose footsteps we are proud to follow.

MS received, October 26, 1973.