Science, Technology, and Society, a Prospective Look: Summary and Conclusions of the Bellagio Conference (1976)

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PREFACE

On June 20, 1976, seventeen scientists convened at the Rockefeller Study and Confidence Center in Bellagio, Italy, under the chairmanship of Dr. Lewis Branscomb, to discuss the role that science and technology could play to help solve some of the major world problems. The seventeen scientists came from eight countries around the world, and represented not only an unusually wide range of expertise in physical, mathematical, and social sciences, but also deep personal involvement in the study of societal problems.

The Bellagio conference was one of a series of scientific gatherings preliminary to a symposium of the U.S. National Academy of Sciences to be held in October 1976, in conjunction with the general assembly of the International Counsil of Scientific Unions. This symposium is in three parts, with the general theme; "Science: a Resource for Humankind". The first part consists of a retrospective examination of the role of science and technology in the social and economical development of seven selected countries. The second part deals with the adequacy of our knowledge base for the successful worldwide management of the quality of the human environment and our natural resources. The third topic is a prospective examination of the role of science and technology in addressing world problems for the next 25 years.

No one doubts the pervasive interactions of science and technology with society, although opinions differ as to the magnitude of good and evil that has come from these interactions. The U.S. National Academy of Sciences felt that in this Bicentennial year of the United States it was appropriate to take stock of the influence that science has had on our lives, and contemplate how best we can ensure that science can be an agent for future progress for all humankind. To the Bellagio participants fell the task of developing exactly this latter topic, the best deployment of science and technology in the service of humankind.

The Bellagio participants came to the conference with an open mind about the extent to which science and technology could or could not address societal problems. It may be argued that as scientists they were biased toward scientific activism. This, of course, cannot be denied. Neither can it be denied however, that many of the Bellagio participants have the best insight into the possible abuses of science and technology, and have even personally championed the prudent use of these tools rather than their deployment for their own sake.

I believe that the Bellagio message is at the same time an affirmation of faith in the fundamental goodness of humankind, and a sobering assessment of the dangers that must be avoided in order to attain a better future for everyone. It is also a moving appeal to all scientists to join forces with engineers, ordinary citizens, and decision makers, in order to address the world problems in a spirit of international cooperation.

It is with great honor and personal pleasure that I introduce the Bellagio call to action to the participants of the National Academy Symposium and the General Assembly of ICSU. It is my sincere hope that scientists worldwide will give it the attention it deserves.

I would like to thank Dr. Branscomb for his leadership in structuring and chairing this conference. I would also like to take this opportunity to express my deep appreciation to the management of the Rockefeller Foundation for offering their facilities to the U.S. National Academy of Sciences for this conference.

Thomas F. Malone
Chairman of the Steering Committee
NAS Bicentennial Symposium

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FOREWORD

"Science, in its pure form, is not concerned with where discoveries may lead; its disciples are interested only in discovering the truth." This view, expressed in 1962 by Alan T. Waterman, Director of the U.S. National Science Foundation, is still held by many scientists. But others demand of science not only subjugation to social values but even pursuit of social goals that science alone cannot reach.

Those who appreciate the beauty and fascination of science are particularly eager to sustain the insulation of scientific activity from excessively utilitarian goals. This desire has been good for scientific progress -- some insulation is essential for the flowering of the most advanced and speculative investigations. Few people outside the scientific community realize what extraordinary scientific progress the last quarter century has produced under exactly this regime of relatively uncircumscribed exploration. The unlocking of the molecular basis for biology is as significant for understanding life processes as was the discovery of the atomic basis for the structure and behavior of inanimate matter. Dramatic discoveries are also being made in other fields such as cosmology, space exploration, high energy physics, and the earth sciences. We have no doubt that such fundamental discoveries viewed from the perspective of history will eventually be recognized as the most important contributions science can make for humanity. Thus, to be true to its own principles and promise, the world scientific community must sustain its commitment to the fullest possible understanding of man and nature.

This conclusion, however, in no way frees the scientist from an obligation to participate appropriately in the process through which this understanding is -- or should be -- applied. The popular view of this process is that science leads, in a more or less serial fashion, to technologies whose introduction is the agent of social change. But the relationship of scientific knowledge to technology is much more intimate than this concept suggests. Technology is as much an agent of scientific progress as science is a generator of new technological possibilities. The two progress in parallel. Moreover, scientific understanding can illuminate the utility, cost and consequences of technolog-

I. INTRODUCTION

Do science and the technologies it gives us offer a realistic hope for a better future for humankind?

Yes, we are confident they do.

Humanity is, for the first time in its history, within reach of managing its fate toward a better life for all. This new condition has been reached through a period of two centuries of intensive applications of science and technology to the satisfaction of human wants. But the benefits of technology have not been shared equally by all nations. A thirst for these benefits is the focus of rising expectations for a better life in many parts of the world still in the grip of poverty and uncertainty about the future.

While much of the scientific knowledge, and many of the technological tools for improving living conditions worldwide are already available, political, economic, and social constraints often frustrate our efforts to apply them constructively. In addition, application of these tools on the large scale that is required poses a threat to the environment, which has been viewed with apprehension, and even pessimism, by many people, scientists and laymen alike. What makes this concern justifiable is not only the magnitude of human activity, which is beginning to compare with that of natural phenomena, but also the lack of full knowledge concerning it, and the fact that environmental impact often crosses national boundaries and must be dealt with in a spirit of cooperation among nations which we have not as yet achieved.

Nevertheless, we believe that science and technology need not be a menace, and can be a blessing in humanity's quest for a better future. We are also convinced that the outcome of this quest will not be determined by a single dramatic effort, or by any single institutional invention, but by the continuous, dedicated effort of people everywhere to use what is known and proven and to take proper account of uncertainty and risk for that which is not. As John von Neumann wrote* in 1955, the proper use of technology in the future depends on "a long sequence of small, correct decisions".

Thus, fulfillment of humanity's hope for a better future requires improved anticipation of long range problems so that they can be dealt with early rather than treated later by hasty repair. It requires increased vigilance to ensure that the technological solution does not create a problem greater than the ones it solves. It also requires the recognition by all that, while expanded scientific and technological input into many social decisions is crucial, it is often just one among many necessary components for these decisions.

Societal decisions involve scientific fact and understanding, but more and more people with varying access to such knowledge want to participate in decisions which affect them. If popular participation is not to lead to disaster, people must have a good understanding of what science has to say about changing global conditions. New knowledge must be disseminated in a form such that its relevance to the social choices which have to be made is as clear as possible. Clearly, the "small correct decisions", of nations as well as individuals, will produce the most constructive results if each decision-maker has the best scientific knowledge of the implications of his decisions, together with a wide selection of alternate technological options.

In the following pages we offer our thoughts on contributions that science and technology can make toward a better future for all. We make no assumptions about major changes in world institutions and attitudes, however much such changes might be welcome. We do see the need for scientists and technologists to rethink their roles and the roles of scientific institutions. We

*Can We Survive Technology? May 1955, FORTUNE Magazine.

think that their role is not only to contribute new knowledge, but also to participate in the creation, evaluation, and application of the right technologies for societal use. We regard the scientific and technological activities as an integral part of society, not the private preoccupation of a technological elite. Indeed, we regard these activities as but one of the major elements of the infrastructure of contemporary societies, embracing discoverers, designers, makers and deciders and, together with users, forming the family of man that shares a common destiny.

II. SOME MAJOR PROBLEMS AND POTENTIALS FOR SOLUTIONS

The world faces serious problems today, which require concerted effort by all nations for their solution. Much has been written about these problems, and the limitations within which solutions can be found. But the limitations are not those frequently assumed. Nature offers us many opportunities to readjust our technologies to solve problems. Nevertheless, some physical limitations, particularly those imposed by the ecological balance of which man is part, are real and must be respected.

We must learn to live with a naturally dynamic ecosystem and not make unreasonable demands for short term stability. Rather, those long term trends that are more likely to determine the survivability of human society must be identified and properly managed. In ecological terms, we urge that greater need be given to *resilience** rather than *stability*. How much freedom of action does this leave mankind? It will take a great deal of research and careful exploration of technologies to find out.

To illustrate the potential role of science and technology, we now discuss four of the major global problems for the next quarter century -- food, environment, natural resources, and arms control. These problems are not selected to set global priorities, but rather to discuss by example some opportunities for the scientific and technical communities, some constraints on their contributions, and some requirements for new decision-making structures.

* *Resilience* (after C. S. Holling) is the ability of a system to absorb, and even benefit by unexpected finite changes in system variables and parameters, without deteriorating irreversibly. In contrast, *stability* describes the ability of a system to absorb very small perturbations about a state of equilibrium.

In each case, we illustrate the need for resilience, the difficulty of accurate predictions, and the importance of social, political and economic factors. Showing through the discussion of each problem are reasons for our guarded optimism toward the future.

Food and Health

Providing the basic needs of the poor, even at the inadequate levels of today, will require much greater effort twenty-five years from now simply because there will be so many more people. The dramatic drop in the death rate in the poor countries since World War II, a result of the introduction of improved sanitation, public health care programs and, most importantly, improved nutrition, has not yet been followed by a corresponding drop in the birth rate (still at 40 per 1,000).

Consequently, while the rich countries are approaching population stability with a growth rate of 0.8% and a fertility rate corresponding to ultimate zero population growth, the poor countries are growing at an annual rate of 2.5%. About 80% of the world population growth is among the poor. In twenty-five years, the 2,800 million people in poor countries will have expanded to at least 4,800 million while the population of rich countries increases from 1,200 million to 1,700 million. To feed the world, the world food-grain production must increase from its present level of 1,200 million metric tons/year to about 2,000 million metric tons/year. If allowance is made for increased incomes resulting in increased meat consumption, or simply for a more nutritious diet for the poor, then the food grain production will have to reach about 3,000 million tons/year by the turn of the century.

Over the last tweny-five years, food-grain production has kept pace with the rising world population. There have been year-to-year fluctuations of course, but the maximum annual fluctuation from the mean never exceeded 60 million tons, about 5%.

This record of increasing food production has been due largely to continuous increases in the agricultural efficiency of the food exporting countries. Smaller increases must be expected in the future because the major inputs, the hybrid grains introduced in the 1930's, the fertilizers and the pesticides are all now approaching optimum general use. Furthermore, most of the high quality farmland is now in use. Yields will continue to increase in the food exporting countries, but logistic, economic and social effects combine to dictate that most of the doubling of food-grain production which will be needed in the next twenty-five years must be obtained from crops grown in the poor countries. It is of crucial importance that a global effort be made to apply and adapt the best existing agricultural science and technology to increase food production in the countries in which the major population increases will occur.

Let us take a closer look at the anatomy of the food problem.

A major factor in food production is the climate. Unfortunately, we can only predict weather about two days in advance. But we can also look at the past climatic record to determine what is "normal" behavior. This record seems to indicate that in recent years we have had unusually favorable climatic conditions for growing. Any return to normal conditions will be a turn for the worse.

Moreover, if an apparent long-term cycle continues we may be at the start of a period of especially bad growing conditions. The severe drought conditions around the world in the 1930's occurred at a similar point in this cycle. Perhaps the recent Sahelian and Ethiopian disasters were warnings. In any case, recent droughts have brought the world's cereal grain reserves to an uncomfortably low level.

If we could predict the climate several growing seasons in advance, it would greatly aid the choice of land use, of strain of crop planted, of fertilizer transportation networks, and of food storage plans. However, prospects for predicting even one season in advance are small, and certainly not realizable within a decade. In the absence of such predictive capability, systems must be designed to be able to produce food under greatly variable conditions. As a first step, international attention must be given to an analysis of the temporal and spatial variations of climate in relation to food production. We feel that clarification of the issues and alleviation of the hazards are well within the bounds of present and prospective technology.

But even without the unpredictable hazards of climatic changes, the fact of the expected geographical redistribution of the world's human population presents us with a grim handicap in the task of doubling the world's food production in the next twenty-five years. Two-thirds of the additional people will be born in countries which are not only the poorest but are also located in the Inter-Tropical Convergence Zone. Rainfall in that region has a seasonal instability far greater than that of the rest of the world. Thus we face an inescapable shift of human population distribution into the areas where, even without any adverse climatic change, crop failures are likely to be frequent.

The magnitude of the task of doubling food production in areas of subsistence agriculture under an unstable rainfall regime becomes more apparent when contrasted with the advantages which have enabled the food exporting countries of the temperate latitudes to achieve continuous increases in food production. These advantages have included a land tenure system which encourages innovation and investment; competent extension services conveying the use of improved crop varieties, hybrids, fertilizers and pesticides; an efficient distribution system stabilized by government price support and storage operations; development of new arable land; and half a century of favorable climate. This powerful productive system will provide yet larger crops, but there is no prospect of overcoming the financial, transport, and sociological difficulties of feeding the increasing tropical populations from the temperate zones.

Technology does provide means for improving agricultural production where it is needed. New high yielding tropical varieties, proven irrigation technologies, faster-growing crops which reduce weather hazards, and major yield responses to fertilizers are examples. The obstacles to their application are mainly political, social and economic. Until both the poor countries and the countries which provide aid give genuine top priority to developing rural areas and improving transport, water supply and amenities for the villages, it will be impossible to feed the growing population and we cannot foresee other than a food crisis of major proportions in many areas.

The continuing rapid population increase in the poor countries is a major handicap. Because of the current age distribution, a major increase in the world's population is inevitable for the remaining part of this century. In order to reach a long-term food-population balance it is critically important to create the policy and institutional framework necessary to contain the rate of population growth in poor countries. We do see hope for accomplishing this, from the following observation. In ten to twelve of the smaller developing countries, there has been a steady and pronounced decline in the birth-rate, with a progresive slowdown in the rate of population growth. (Korea, Singapore, Taiwan, Sri Lanka, Mauritius, Hong Kong, Trinidad and Tobago, Costa Rica, Chile, Puerto Rico, and probably also Egypt, Tunisia and Guyana). These countries appear to have a number of characteristics in common -- a relatively high life expectancy and literacy rate, relatively high incomes, a fairly high status of women, a comparatively equitable income distribution, a good communication system, and a fairly effective family planning program. The case of Sri Lanka in this group is of particular interest because, despite a relatively low per-capita income, it shares in most of the other listed characteristics. The results achieved in these poor countries are persuasive evidence that the pursuit of appropriate economic and social policies, and not just programs of family planning, can make an effective contribution to reduction of population growth.

Since population stability and food self-sufficiency seem to be dependent on balanced social and economic development, access to scientific and technological skills in health care may be more than just a humane requirement. The well-being of people around the world is still strongly limited by sickness and poor nutrition. As many as half the people of the poor countries are sick much of the time. Proper nourishment would prevent much of this disease. The malnourished young children of the poor countries are much more vulnerable to childhood diseases than the children of the rich countries. Older children and adults suffer from bacterial and virus infections, from parasitic diseases, and from the effects of nutritional deficiency. These illnesses greatly lessen their ability to work, but also increase their physiological food requirements.

Considerable improvements in health and lowering of mortality could be accomplished with presently known techniques given the proper socio-economic conditions. For example, trachoma could be reduced by increasing the quantity of domestic water supply available for washing and bathing in rural areas. Delivery of health services in the rural areas of poor countries would be greatly enhanced by a systems approach as well as by a more widespread appreciation of the problem.

It is clear from the above discussion that feeding and caring for the world's population is not a problem that either requires or can be solved solely by a dramatic new invention. It does call for some new scientific and technological development. But, even more importantly, it calls for concerted action by the technical community and the society at large to apply many available technological tools with the sense of urgency that the problem deserves.

Environment

Over the past decade, the danger of altering crucial natural cycles in the environment has been receiving increasing attention. This attention is motivated both by the advances in measurement technology and by the growing scale of human activities. Unfortunately, however, major decisions concerning the environment must still be made using best guesses based on only sketchy knowledge.

By and large, we lack the understanding necessary to estimate whether or not a given natural system is resilient, before the threshold is reached beyond which the system irreversibly deteriorates. On a regional level, there have been many instances in which this threshold has been passed. An example is *desertification* resulting from improper agricultural practices. On the other hand, there are also counter-examples in which removal of the stress allowed a return to an acceptable, if somewhat different, state.

In theory no environmental change is absolutely irreversible. The environment can be restored with sufficient effort, money, and technical skill. But in practice a distinction must be made between changes which are effectively irreversible and unacceptable, such as desertification, and those in which it is reasonable for society to weigh the benefits from a temporary environmental change against the cost of correcting for it or reversing it later. The 19th century economist, David Ricardo, viewed environment as a national capital and advocated caution against its destruction. One can make the valid argument that there are instances when this capital can be used to create new wealth, part of which can be subsequently used to restore the original environmental capital.

Irreversible, or possibly irreversible, perturbations are causes for great concern, particularly when they occur on a global scale. For example, concentrations of certain compounds related to human activity have increased noticeably above their natural levels in recent years. Nitrogen fertilizer manufacture, for instance, is beginning to compete in magnitude with global processes in fixing nitrogen. Its effect is in dispute, but what is not in dispute is the fact that we are altering the natural system in what *can* be an irreversible manner. A much better understanding of the dynamics of the natural system is needed to predict the effect of these perturbations.

Another example concerns the carbon dioxide concentration in the atmosphere, which has been steadily increasing in recent years, paralleling the increased combustion of fossil fuels. The implication of this increase for climatic modification is unknown, but a persuasive case can be made that it could become a major problem.

To wait for definitive detection of climatic effects before taking corrective action may be dangerous, particularly since man-made effects will be superposed on often longer natural fluctuations. Rather, such effects have to be anticipated on the basis of scientific understanding of underlying mechanisms. This in turn requires the development of refined models of the atmospheric system on which artificial perturbations can be tested. It was on the basis of such models, admittedly still crude, that the effects of fluorocarbons and SST exhaust on the ozone layer were estimated, though the precise magnitudes of the effects are still a matter of debate.

Meanwhile, technological options should be developed for correcting harmful consequences of environmental interventions. For example, should the increasing concentration of carbon dioxide be found to be a major problem, a contingency plan might be developed for carbon dioxide removal, or deep ocean disposal. Conversion to non-fossil energy sources such as breeder reactors or solar energy might be accelerated. In any case since CO_2 concentrations are globally dispersed, they must be controlled by global agreements which may involve significant compromises of national sovereignty.

The introduction into the environmental of synthetic compounds, while easier to monitor than the introduction of natural compounds, leads to effects just as difficult to predict. In this case the major concern is that of an unknown chemical reaction somewhere in the environment which could alter a natural system. The methylation of mercury is one example, fluorocarbons another.

Unfortunately, the work required to identify new reactions and establish their significance must often be done with minimal understanding of natural systems. Traditional scientific institutions are not very well equipped to deal with preliminary and tentative information regarding such reactions.Because of the interdisciplinary nature of the problem and the need for preliminary alerting of decision makers, the release of even tentative evidence and conclusions is desirable. Yet such release outside the self-correcting arena of the scientific communication system runs the risk of creating unnecessary economic dislocations and is often inconsistent with scientific rigor.

Complicating the search for compounds hazardous to humans and to natural systems is the fact that two or more may act synergistically -- that is, their combined effect when acting together is greater than the sum of their individual effects. For example, the carcinogenic effect of cigarette smoking and of airborn asbestos acting together is greater than might be expected from simply combining the carcinogenicity of the two. Such effects broaden the scope of risk assessment even further.

Even when a clear understanding of the hazard is available, a trade-off must often be made which involves economic, political and social considerations. Over the next twenty-five years, such decisions will increasingly have international implications, because of both the economic and the environmental interdependence of nations.

The role of the technical community is clear -- to monitor, to assess risk, to pursue leads energetically, to develop options for decision makers, to communicate new evidence and interpret its implications responsibly and with proper attention to uncertainties, so as to assist decision makers in arriving at the best possible anticipatory actions.

Materials Resources and Energy

Neither the basic needs of a growing population nor control of insults to our environment can be accomplished without an adequate supply of natural resources and energy for the future. There are serious questions about the adequacy of existing resources of raw materials and energy fuels. Such resources are, in fact, extensive but must be seen as functions of price, geological assurance, and environmental implications.

It is important to understand that because a shortage of a certain resource raises its price, great intensity may be brought to the search for a new source or a substitute. Thus, the adequacy of a resource is a function of the availability of technological alternatives. Sufficiently assured resources, with production costs below acceptable thresholds, are considered reserves. Figures for reserves, therefore, refer to a given economical and technological situation.

Thus, the recently popularized view of our habitat as "Spaceship Earth", with mankind steadily consuming a finite stock of resources, may be misleading . Very little is really lost from the earth; it is mostly put in less accessible form, from which it can eventually be recovered at a price, given the appropriate technology. Thus, the extent of raw materials resources effectively depends on the acceptability of higher prices or new technology to cover extraction, processing, substitution, and environmental impact. This is especially so when energy consumption for the production of such raw materials is not a constraint. Thus, *energy is very much the basic resource.*

For more than a century the situation in developed countries has been characterized by declining raw materials costs, in general, and declining energy fuel costs in particular. This has been due to a combination of technological advances and economies of scale. For example, since 1945 the cost of electricity has declined by more than a factor of 3 relative to the consumer price index, while the relative cost of a barrel of oil is less than half. The present talk of scarcity of raw materials and fossil fuels is made in reference to departures from this long-term declining trend. There is now general awareness that such a trend could not continue forever. We cannot escape an eventual exhaustion of cheap reserves in a few decades, at most fifty years. In particular, the inexpensive sources of oil and gas in the Middle East are probably a one time gift of nature. Future petroleum discoveries, if any, are likely to be off continental shelves in increasingly deep waters, in hostile areas such as the Canadian arctic, or in remote areas such as the interior of Siberia or China.

Oil and natural gas offer unique advantages for uses other than as fuel for electric power plants. Both serve as fuel for transportation vehicles. Oil is a feedstock for chemicals, especially plastics, and natural gas is especially useful in industrial processes requiring careful temperature control, and in the nitrogen-fixation process for fertilizer.. Thus, the future value of oil and gas as raw materials may be much higher than their current value as energy resources.

On a larger time scale of fifty to seventy-five years, several options exist for a very large, or even practically unlimited, supply of energy: nuclear fission with breeder technology, several alternative solar technologies, nuclear fusion, and coal with new technology. Since it is not obvious which of these options will be successful, it is imperative that a stockpile of energy technology options be developed. Any one of these options, or combinations, would allow the use of low-grade ores for the production of raw materials, but each is expensive. It is expensive first in a monetary sense, particularly in capital investment requirement which will probably be significantly higher than that for oil and gas. Each is also expensive in terms of societal and environmental impact. Moreover, very large uncertainties presently surround estimates of the magnitudes of costs and environmental risks.

Special care has to be taken in exercising any of the above options in order to minimize residual risks and impact on the environment. In particular, exercising the nuclear fission option on a global scale entails not only a potential environmental impact from possible accidents, but also the danger of proliferation of nuclear weapons. International cooperation in managing the production of nuclear fuel, and the disposal of nuclear wastes, is imperative in order to minimize this danger.

In any case, future systems for the production, handling, and use of energy, and the production of raw materials from low-grade ores, will require extensive changes of the existing infrastructure (transportation, storage, labor usage and industrial processes). Among the most important constraints for such an adaptation are the following:

- The requirement of gradual transition. (In the past, transition to a new fuel or raw material source has usually required 25-50 years.)

* Geographical distribution of facilities and other elements(which differ for each energy technology, and have implications for land use planning and power transmission facilities).

* Evolution of environmental and safety standards and regulations.

* Requirements for capital and skilled labor.

Energy conservation and materials recycling have to be part of both the new infrastructure, and a transition policy toward this infrastructure. Of course, energy conservation and materials recycling must be seen in the context of their economic implications; namely, conservation opportunities must be weighted against their capital, labor, and energy requirements. If it is indeed true that we face a rising cost trend for energy in the future, then the historical trade-off between investment in increased energy supply and investments in efficiency of energy end-use will change. With higher prices, and especially if environmental costs of new supply are fully internalized, the savings from a dollar investment in end-use efficiency may exceed the return from a dollar investment in energy supply. In other words, in a rising cost environment conservation will make more economic sense than increase in supplies, in many more instances than has been true in the past.

Since the cost of raw materials in usable form is closely tied to the price of energy, the economics of materials will also tend to shift in favor of materials recycling, materials thrift in design, and substitution of materials based on more abundant raw material sources. To the extent that materials recycling is both economically and technologically feasible, materials are a renewable resource. But products must be designed with ease of recycling in mind. To some degree, such recycling design will be market-driven in the coming years. To the degree that is it not, because of market imperfections, institutional arrangements must be made to ensure that it is given proper attention.

Science and technology can lessen the impact of materials shortages by increasing our options of substitution of one material, possibly a synthetic one, for another. This capability can reduce the requirements for stockpiling, and consequent depletion of world resources. On the other hand, international agreements may be required to prevent or correct disruptive effects of material substitutions. For example, a high commodity price may stimulate R & D leading to displacement of the expensive commodity, which in turn may have a serious effect on the economy of a country critically dependent on exports of that commodity. Ultimately, stability in prices and availability of resources will be best assured when the countries of origin share in the creation of the added value that contemporary technology brings to raw materials through manufactured products.

Arms Control and Nuclear Proliferation

One of the most ominous developments of the last thirty years is the worldwide technological arms race. The East-West component of this arms race has already led to the creation of both the hardware and the software for killing some five hundred million people, almost entirely from among the populations of the technologically most advanced countries, in less than one day. This component of the race seems to be past its most dynamic phase, and the prospect for marked changes in either direction are not great. Because of what is somewhat loosely called the "overkill" capacity of the nuclear weapons systems, neither fractional changes in numbers nor evolutionary changes in doctrine can really change the situation very much. In addition, at the moment there are in sight no qualitative developments which are likely to change the situation appreciably.

The North-South and intra-South components of the technological arms race are in their earliest stages, but all signs point toward rapid worsening of the situation.

Within the developing world, the dissemination of nuclear technology accompanying the spread of nuclear energy, is generating a new potential for the proliferation of nuclear weapons. This promises to have deep and not entirely foreseeable political consequences, including the risks of triggering a large-scale use of nuclear weapons.

The arms race, both conventional and nuclear, is obviously a major concern of mankind. The character and level of the threat from nuclear war to human survival is the direct result of the highly sophisticated technology involved. To produce this technology, many governments have engaged significant fractions of the scientific and technical capabilities of their countries. Thus, the role of science and engineering has not been a passive one in this instance, but rather a very leading one. It may even serve as a model of mobilization of technologists for the attainment of national or transnational goals of a more benevolent nature.

In all the nuclear weapons states, the designers and builders of these weapons built them in order to achieve a number of widely endorsed political objectives: getting them before some enemy did so; accelerating the end of a long and terrible war; or redressing the local or regional military balance. Certainly, some of these objectives were achieved. In the net, however, the result can be described as achieving stability in the short term at the risk of catastrophe in the long term. Indeed, a world with gigantic overkill in place is the ultimate example of the sacrifice of resilience to stability. If the deterrent should ever be used, civilization as we know it probably could not recover from the shock.

The main problems posed by the East-West arms race are the enormous potential for death and destruction inherent in the systems now in place and the bad example it sets for the rest of the world. Our efforts should, therefore, be directed towards preventing the use of these weapons in the short run, and eliminating them in the long run. This can probably best be done by insistently focusing attention on the dangers inherent in the present situation, and by promoting detente and all related policies toward increasing communications and relieving tensions. Mutual deterrence is probably not a viable posture for the world in the long term, and becomes less so as the deterrence becomes multilateral rather than bilateral.

The North-South and intra-South arms races pose a somewhat different problem. They consume human energies and physical resources badly needed elsewhere: they make nuclear war more likely simply by placing the power of decision in more hands; and they threaten in the long run to become one of the tools through which some of the have-nots may seek to acquire what they consider a just share of the world's goods. The efforts of the North, therefore, should be directed towards correcting the bad example these states currently provide, towards slowing the diffusion of the most dangerous elements of nuclear hardware and software, and towards providing assistance for meeting the critical needs of the South.

The issues related to arms control, disarmament, and the proliferation of nuclear weapons capability are not only of vital importance to the future of society but turn on the interplay between complex political issues and highly technical questions. Despite the security restrictions that conceal much of the information from public view, there are opportunities for scientists and engineers to inform themselves on the major issues, and participate in the search for progress in this field. Indeed, the technical and policy aspects of arms control are deserving of international research effort, in the same way such efforts are helpful in the solution of other major problems of society involving substantial technical questions with global applicability.

Notwithstanding any technical contributions to the resolution of the arms race problem, ultimately this resolution must be made in the political arena. In this respect, scientists and engineers can make two important contributions: they can increase the awareness of the disarmament issues by scientists all over the world; and they can strive to slow down the arms race, through involvement in the political process. The objective must be to slow down the current dangerous course to the point where the evolving political institutions of the world can cope with it.

Finally, it is clear from the rest of this report that the past and present products of science and technology will form an essential element of the means for meeting the critical needs of the world's people, especially those in the so-called *third* and *fourth worlds*. A larger part of the efforts of scientists and engineers generally must be devoted to meeting these needs. The main reason for doing so is simply because it is right; but an important secondary reason is to avoid the development of the kind of chaotic and rapacious world in which recourse to nuclear weapons may some day somewhere seem the only promising way to escape misery.

III. SOME BASIC REQUIREMENTS AND PERVASIVE CONSTRAINTS

The solution of the global problems we have discussed involves not only specific difficulties in each area, but also some general requirements and constraints. Prominent among them are: availability of capital; opportunities and difficulties in increasing productivity; equitable sharing of the fruits of productivity increases, reflected in the growing movement for improved *Quality of Work*; and cultural constraints. Let us consider them briefly in turn.

Capital Constraints

While it is possible to envision with some confidence that, within the next quarter century, scientific and technological approaches to the solution of the global problems discussed above will be well within reach, there is no doubt that massive new investment will be required to realize the benefits of technological advances, especially in the developing countries.

The issue of capital availability to meet these new challenges has a somewhat different connotation and significance in the industrialized societies as compared to developing societies. In the industrialized countries, with a gross domestic product of $3,000,000 million equivalent, and a current investment rate of as much as one-fifth of this gross domestic product, the main problem will be to create the necessary mechanism and financial incentives to mobilize and exploit the new, capital intensive, high technology areas. Without a deliberate and organized effort to create the necessary conditions for attracting resources into these areas, there is a serious danger that the financial marketplace will not adequately take into account the technological opportunities which are opening up, particularly in view of the time that is sometimes required before such opportunities can come to fruition.

The developing countries, with a population of close to three million, a gross domestic product of only about $600,000 million (excluding the oil producing countries), and domestic investments perhaps only about one tenth of their GDP, will have to continue to depend on a large and growing net transfer of capital from the industrialized countries. Currently, the total net capital flow from the industrialized to the developing countries is in the range of $30,000 million, which is 1% of the gross domestic product of the industrialized countries. The resolution of the food-population crisis, and the implementation in the developing countries of development programs in other important fields, such as materials and energy, will require a substantial increase in the present levels of this resource transfer to the developing world. However, we do not see these requirements as becoming a significant and unbearable burden on the present economic situation or prospects of the industrialized world. In addition, more effective application of science and technology toward better utilization of human and material resources in the developing countries should itself generate additional capital to sustain and strengthen the growth of the world economy as a whole.

Productivity and Economic Development

None of our hopes for mankind can be realized without continued economic development. Striving for the solution of world's problems will inevitably exert inflationary pressures worldwide. In order to raise the living standards of the developing nations without substantially reducing those of the developed ones, steady increases in capacity of existing capital, facilities, and human resources to satisfy the general needs of society must be made. We have specifically pointed out that the materials and energy needs of all nations can be met, but only with technological progress that will involve major investments. These costs must be offset as much as possible through efficiency improvements. For all these reasons research and development is needed to improve productivity.

In a capital-short world, the most powerful sources of productivity increases are new technologies, and the effective engagement of well trained people. Research, education and engineering are major sources of these productivity enhancing capabilities.

Productivity increases are most effectively achieved when an innovation produces a significant reduction in the materials, labor, or capital consumed to accomplish a given task. Whether or not such an innovation takes place depends particularly heavily on the rewards for successful innovations, and on the existing stock of basic and applied scientific knowledge. Such innovations often bring with them not only the potential to perform old jobs better and more efficiently, but totally new functions as well. This stimulation to the economy may of course be offset to some extent by costs associated with the requisite social change, or other indirect effects, all of which must be properly managed.

More frequently, productivity gains come about through incremental engineering improvements in efficiency, and in particular through reduction in cost or in materials consumption. In this way, tolerances and design margins are reduced and industrial efficiency is increased. Thus industrial societies deliberately strive to reduce margins as a reduction of waste. Obviously, this otherwise desirable strategy is increasingly vulnerable to unanticipated dislocations in the material supply and costs, or changes in the regulatory environment.

The present high productivity levels in the industrialized countries were achieved through a number of innovations in the production process, such as application of power sources, assembly line production process, component interchangeability, automation, etc. The potential of some of these techniques appears to be nearly exhausted. For example, little additional productivity can be expected from further application of power, or from piece parts assembly. On the other hand, we have just begun to realize the benefits from some other innovations, such as the use of computers for design automation, improved man-machine interaction, and process and assembly automation.

Thus, productivity increases are likely to continue in those industrial countries that are committed to continued investments in industrial R & D. One possible area of concern is the increase of productivity in parts of the service sector, which has generally lagged far behind that of the industrial sector. In this connection, the rapidly developing information technologies offer a major opportunity for substantial productivity improvements.

The situation is substantially different in the developing countries. There, productivity increases are urgently needed in all sectors of the economies, and they can be obtained either through application of available technologies, or through advanced technologies that are particularly appropriate for the local conditions and constraints (for example, solar energy technology for sun-drenched countries with inadequate distribution facilities). Since developing countries must avoid simple emulation of R & D activities of advanced countries, which are often unsuited to local needs and conditions and may absorb unwisely scarce scientific skills of the poor nations, special care is required for appropriate development of these indigenous technical capabilities. International groups such as CGIAR*, can play a very important role developing and adapting technology as needed to foster a rapid increase in the productivity of developing nations.

*Consultative Group for International Agricultural Research, an international but non-governmental organization for coordinating financial support and research strategy for a group of highly effective international research centers around the world.

Technology and Quality of Work

The benefits of increased productivity in industrialized countries, have been shared by capital, labor, and the consumer. In particular, work conditions in production have been improved, and the concept of *quality of work* has begun to emerge as a focus of attention by labor. To the extent that labor's desire for further improvements of the quality of work impacts the rate of productivity increase, it competes with other objectives of many countries. While today this is a subject of concern largely in the industrialized countries, it will undoubtedly become the concern of more and more countries, as they manage to satisfy the basic needs of their populations and their labor forces.

The thrust of the quality of work effort goes beyond mere increases of wages, or reduction of working time. Discussion of working time does not only involve the number of hours per week, but also paid vacation, gradual retirement (with pension), less shift work, flexible working hours in the day (or in the week or month), plus the right to take time off not only for reasons of health but also for personal business or family care.

In many countries, organizations of workers seek more active roles in decisions which impact the work environment, even to the planning of research and development. In this way they seek to internalize the benefits of the productivity contribution of R & D in order to improve the quality of their own lives. We must recognize that this very understandable desire exerts additional pressures on the need to steadily increase productivity and at the same time make the production process more congenial to workers.

Cultural Constraints

Fundamental to addressing all of the above issues are questions of human motivation and values. Scientists must, of course, avoid falling into the trap of imposing their own values on all those who are expected to benefit from scientific progress. Frustration of our hopes from science and technology may result from a failure to assess correctly the needs and aspirations of people. It may also result from tendencies of the scientific community to set themselves apart, and thus fail to communicate effectively their understanding of technical realities and possibilities.

In the context of the present discussion, the main goal we are addressing is to find a way for all countries to solve their collective and individual problems and share the benefits of the scientific and technological revolution in accordance with their own aspirations. People in industrialized countries are often, quite properly, concerned with the danger of upsetting the culture of a less developed country through introduction of modern technology. In this connection, however, they often show more concern than the countries in question themselves.

The technological revolution is a revolution in innovative power. Sharing in the technological revolution involves sharing in this power, which in turn requires a transfer of technology to less developed countries. But this transfer is not a simple matter of transfer of technological operations, or know-how. It is very difficult for a developing country to absorb any technology more complex than the level at which the country has the power to contribute to, as well as to scrutinize and control the innovative process. Simply stated, the level of technical literacy in the developing countries must be raised if they are to share in the fruits of the technological revolution.

More often than not, the technological revolution increases uncertainty, as each new stage perturbs existing knowledge, existing price structures and distribution of power, and as increased choices relieve the existing constraints on human unpredictability. Recognition that increasing uncertainty may accompany technological development should give the technologist a realistic perception of his role, and also help establish a rational public assessment of the power of technology.

The technological revolution means that a high price will increasingly be commanded by technological knowledge. Developing countries are well aware of the cost of knowledge, as they compare the prices of their raw materials with the prices of goods manufactured from them. The world will be knowledge intensive in specialized areas linked by the common language of mathematics. The trend in a knowledge intensive world is for the lay public to have more knowledge of science, while at the same time scientists have increasingly extensive knowledge of social, economic and political matters. In this world, scientists and engineers are likely to experience the problems and temptations of a priviledged (but not necessarily powerful) elite.

One major problem is that society in a knowledge intensive world often tends to become stratified and compartmentalized, making common understanding rather difficult. In such a situation, there may be a temptation for the scientists to draw a boundary around themselves limiting communication with outsiders. Thus, scientists run the danger of excluding exactly those people with whom they must share their knowledge if they are to make a contribution toward the solution of world's problems.

Perhaps it would be helpful for scientists and engineers to draw some lessons from a model of culture that applies to all societies. According to this model, an elite class generally supposes that the apparent irrationality of the surrounding population, its slowness to learn, or its lack of motivation are fixed either by innate capabilities or by a rigid cultural background. But neither theory can be justified. A good reason for rejecting such explanations is that they inhibit the search for variables relevant to the attainment of goals. The main message of contemporary anthropology on cultural constraints is that they are not rigid, but culture is more flexible than has been popularly supposed. Seemingly irrational behavior in decision making should not be dismissed as mystical, or primitive, or due to cultural bias, until a thorough examination of the cost structure involved in decision making, and the local distribution of power, have been made.

IV. CONCLUDING REMARKS

We have given a view of the world today -- its problems, and prospects for their solution -- from the perspective of concerned scientists. It is not a view of impending doom, but neither is it a view that justifies complacency or procrastination. Rather, it is a sobering view of a great challenge, together with an assertion that the world *can* reach the goal of a better life for all humankind, if it can charter a prudent course through troubled times, and if a lot of people make their share of correct small decisions. We assert that science and technology are not obstacles to the attainment of this goal, but rather necessary agents, both for making those decisions and for carrying them out.

Fulfilling people's expectations will not be easy. The magnitude and complexity of the needed activities challenges capabilities for making and implementing wise decisions, and even competes with natural environmental forces. Science may provide technological options to relieve the constraints of environmental effects, raw materials supply, and even energy resources -- but it may also have to provide large productivity improvements to pay for these options. To successfully address some global problems, scientific and technical skills must be much better distributed globally than they are today. And we are faced with the fact that many of the technological contributions to human progress today are aimed at short-term benefits at the potential expense of long-term resilience -- leaving an ominous legacy for future generations.

But, on the positive side, we have never had, in the long history of humankind, so many tools available for constructive effort, or even so much awareness of the need to act in a spirit of international cooperation. The power to ensure that science and technology have the opportunity to make their full contribution to satisfying human aspirations does not lie in the hands of scientists and engineers alone. But the failure of the world's technical community to commit itself to this end and insist on the development of needed policies, institutions, and cooperative activities could make the pessimistic view of doomsayers a self-fulfilling prophecy. So, it is appropriate that we end this discussion with a call for mobilization of this spirit of commitment on the part of scientists and engineers.

To our colleagues and fellow citizens of the world we address the following appeal:

1. Improve the Process for Generating and Managing the Introduction and Evolution of Technology

The fruits of fundamental research are only identified in retrospect, but applied research and engineering can and must be purposefully directed to human needs. It is naive to assume that needed technologies will become available just because the necessary science exists. Technology must be effectively encouraged. In making technological choices it is difficult, and possibly unwise to suppress attractive but potentially harmful technologies before the benefits and risks are evaluated. But it is also dangerous to wait until irreversible harm is threatened before technology assessments are made.

Assessment must be an on-going process, accompanying the evolution of technology. Processes must be developed that will permit a greater variety of technologies to be experimentally introduced and thereafter closely monitored so that appropriate choices and adjustments can be made at several stages. Laymen and professionals, hard and soft scientists, academic, industrial, and governmental sectors all need to participate. Much greater flexibility than we now have for readjusting technological strategies to new findings will be needed in the future; more imaginative engineering will be needed to develop better options; more scientific understanding will be needed to support wise choices among them. In this process, it is as much the responsibility of the engineer to be alert to consequences of his technological contributions as it is for the scientist to help create healthy foundations for useful technological alternatives.

2. *Create the Institutions, and Provide the Facts and Analysis for Anticipatory Decisions*

Political leaders and decision makers generally understand the need to anticipate future consequences of present decisions. Too often, however, they do not understand the time scales over which the consequences may fall, the potential cost of reversing adverse effects once they become apparent, or the range of technical alternatives or contingency plans which might be possible. Better ways than presently available are needed to bring early warnings to public attention, but they are not enough. Scientists must work to create new problem-oriented institutions for both scientific and policy research, experienced and credible enough to deal with problems so riddled with uncertainties that hypothetical situations must be modelled as the basis for public decisions.

The needed institutions must have a degree of stability, continuity and breadth of expertise beyond that available in comparable institutions today. The new circumstances facing humanity require a serious and permanent commitment for coping with technical complexity in decisions affecting the future. Thus, these institutions must take account of long-term threats to the resilience of the systems on which people depend. This may require the sacrifice of some measure of short-term stability or benefit to protect against very large, long-term risks. Scientists and engineers must also get involved in efforts to improve society's ability to provide contingency planning for the corrective action necessary when a suspected technological risk materializes.

3. Share with the Public a Sufficient Understanding of Risks and Technical Alternatives to Support Wise Public Policies

Those scientists concerned about the contribution of science to world affairs have long recognized the need to inform and advise public leaders. In the coming decades, it will be increasingly necessary to also inform the general public on scientific conclusions relevant to policy making, because the public's sense of priorities and values limits the decision options of its leaders. Frequently, society must forego immediate benefits for the sake of long-term safety or gain. Unless the public understands the reasons for such decisions, it is difficult for the political leadership, however enlightened, to provide the technical community with the opportunity to make the best technical choices.

Expert judgments will always be needed -- which can be evaluated and used by other experts. But the public measures scientific credibility by a standard unfamiliar to many scientists -- the ability to communicate outside the group of recognized experts in one's field. This situation poses opportunities, but also temptations which can lead to corruption of the integrity of the scientific process.

Finally, a great deal of work must be done to understand and help clarify public perceptions of risk. Great difficulties are encountered in public policy today with respect to those risks which are very small, but which involve unacceptable consequences.

4. Evolve and Sustain New Standards of Scientific Rigor Appropriate to Research in Support of Early Warnings and Policy Decisions

Public issues are multidisciplinary, crossing the boundaries of both social and natural sciences. The traditional standards of rigor in a discipline, and of criteria for professional career advancement, are not always applicable to interdisciplinary efforts. What constitutes convincing evidence is not always the same in science, engineering and economics. The information a decision maker wants often is the best answer given the present state of knowledge. But bringing to the attention of society a potential long-range danger often requires divulging tentative observations. Nevertheless, the accuracy of the estimates and the underlying assumptions must be rigorously and explicitly stated. In the absence of standards, we recognize this struggle for rigor is difficult -- but it is necessary.

The values by which scientists judge one another must, therefore, undergo an evolution which elevates the incentives for responsible professional performance and high-quality research applied to problems of public importance, and communicated in a timely manner. This task must be undertaken by professional societies, international unions and scholarly institutions; it cannot be left to either legal or political institutions.

5. Promote the Diffusion of Scientific Capability and Information Throughout the World, Especially With and Among the Developing Regions

We are convinced that the opportunity for technology to expand the effective resources of food, materials, and energy requires a rapid improvement in the indigenous professional and technical capabilities of every region of the globe. The ability of the poor countries to absorb technology -- native and imported -- is limited by the professional and technical strength of their human resources and their institutions. Even if much of the technology needed by poorer countries is to be imported, those countries must be able to make their own evaluations and choices. This will be an increasingly technical task as the technology strategies of industrialized countries change to meet their own needs.

The world's scientists should, therefore, commit themselves to new and more effective approaches to technical assistance and cooperation. This is worthy of emphasis, not only because of the urgency of unmet human needs, but also because of the rising threat of technological protectionism and the persistence of impediments to free interchange of science and scientists among the various parts of the world.

6. Strengthen International Frameworks of Decision-Making for Global Issues

The common feature of every major world problem that we have discussed is that solutions require concerted action by people of many nations. But nationalism is too strong and, with few exceptions, today's international institutions are too frail to provide the proper framework for mobilizing science and engineering on a global scale to solve these problems. However, the exceptions are encouraging and the existence of a worldwide scientific and technical community whose common bond of understanding and mutual respect transcends national boundaries is a great asset. Through this community, national as well as international research centers can be linked to provide a common basis for global decision making on transnational issues. But above all, increased harmonization of national policies is essential to avoid a *tragedy of the commons* on an international scale.

7. Explore How the International Scientific Unions Can Enhance the Contribution of Science to the Solution of World Problems

Our appeal to scientists is addressed not only to each individual scientist, but also to our professional associations, academies, and unions. The stresses we anticipate concerning personal career choices, and standards for scientific rigor, are reflected in similar questions for these scientific institutions. The dependence of the people of the world on enlightened and imaginative application of scientific skills to fulfilling human hopes and needs presents these institutions with a difficult challenge. The scientific unions must preserve and extend their effectiveness in behalf of scientific progress and the diffusion of knowledge. But science and technology are powerful agents for change, and it is important that this change be in concert with people's aspirations and values. Scientists -- at least most scientists -- must not view themselves only as the custodians of knowledge, aloof from world affairs, nor should engineers ignore the broad significance of technological alternatives they conceive and create. In the next quarter century, the institutions, goals and values of scientists and engineers will not be immune from the forces of change, but must also evolve. Properly guided -- with the participation of scientists and engineers themselves -- this evolution could not only facilitate effective answers to the world's most pressing needs but ensure the continued vitality and progress of science itself.