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New Technologies with High R&D Intensity

- Overview and Technology Development strategy -

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It is intended in this paper, to present the trend of new technologies with high R&D intensity and the technology development strategy of developing countries. Among these, one area of paramount importance is materials technology development. In order to steer the development of new materials technologies, problems of how to set objectives for technology development, what guidelines to follow for technology development, and what R&D system to use, are discussed.

Particular emphasis is placed on the strategy of technology development. Examing the pattern of research and development, it is classified into three categories: first, improvement of existing technologies; second, development of composite technologies; third, creation of innovative high technologies. The perception and facets of technology vary among the different phases of socioeconomic and industrial development of countries. Viewed from such a technological perception, an adequate technology development strategy for newly industrialized countries (NICs) such as Korea is proposed. The focus of their technological operations is improvement of existing technologies and some generation of composite technology.

1. TREND IN SCIENTIFIC AND TECHNOLOGICAL INNOVATION

It is useful in deciding the direction of future development to examine the world trend of technological innovation most advanced nations pursue. As is well known, one characteristic of modern technology is the improvement of existing technology. Thus, advanced countries constantly try to elevate their industrial technology through increased sophistication and elaboration. Elaborate and efficient design and manufacturing technology, using computer applications and the sophistication of a chemical process due to a new catalyst, are expected to accelerate the development of the present machinery and chemical industries, respectively. In the fields of fine chemicals, materials and precision machinery, where the most important factors are purity, accuracy and highly sophisticated functions, better performance through the creation of new functions and higher degrees of purity and accuracy are constantly pursued. A common factor of these new technologies is that they are brain-intensive. Another aspect is the increased elaboration and integration of related technology that has enabled the development of the fifth-generation of computers in less than half a century.

A second characteristic of modern technology is that the technological projects advanced countries are endeavoring to develop tend to be large scale, such as atomic energy, space exploration, ocean development and specific defence technology. They require both enormous research expenditure and great research manpower on the one hand and a long gestation period for development on the other. It is therefore difficult for a few enterprises or institutes to undertake such projects alone, so a national undertaking becomes inevitable for multidisciplinary, organized, cooperative research and development.

A third characteristic is the development of breakthrough technology. Common technological progress can be considered as continuous, but technological innovation does not occur continuously. It is often observable in the history of science and technology that the development of technology proceeds continuously for a certain period of time and then stagnates. The birth of a seed technology is an absolute prerequisite for breaking through this stagnation. Once developed, these 'breakthrough' technologies transform an existing system into a completely new one. There are indeed numerous such examples throughout history, including the computer, radar, penicillin, the jet engine and so on.

Fourthly, in recent years a visible increase has been made by advanced countries in the development of welfare-related technology. These include technology to improve the living environment by reducing various kinds of pollution, increasing protection from both natural and artificial disasters, and improving the quality of life by upgrading the level of nutrition and public health, etc. In addition, a broadened infrastructure with an efficient transportation system, modern communication network and the rational use of land is another priority area in this regard.

A fifth characteristic is soft science for the knowledge industry. Due to the complex and diverse nature of the knowledge industry, the necessary technologies are very complicated and sophisticated. Take the example of an engineering consultancy service. The advancement of industrial structure and a high degree of specialization, now require a heavier weight of sophisticated engineering. Successful engineering is only possible with a total system approach which should integrate systems involving finance, design, service and production in addition to the conventional system of science and technology. Hence, promotion of the knowledge industry inevitably necessitates the development of so-called "soft science and engineering" covering a wide spectrum of knowledge, not only for the natural sciences, but also for the social sciences ranging from economics to psychology.

These technologies, which have been described from various angles, are being developed at a very fast rate. The speed of innovation for previous technology generally did not exceed that of a business cycle. But the speed of major modern technological innovations, particularly in the fields of semiconductors and computers, is often faster, thus causing observable disturbances in market equilibrium. Hence, the implication is that technology can no longer be treated as a residual variable in understanding the economic behavior of relevant industries. Therefore, technology should now be understood as a major factor in economics.

The decade of the eighties was characterized by an unprecedented pace of development of new technologies and rapid changes in their adaptation and use. The initial forms of these technologies were mostly prevalent and used in the seventies in developed countries. In the eighties, some of these technologies have penetrated the markets of virtually every developing country. These changes are forcing many developing countries toward a major redirection of their "Science & Technology" efforts. This calls for a clear understanding of the nature and potentials of the technologies in the particular context of different countries, beyond the euphoria or the panic often associated with them.

No other topic in recent memory has evoked as pervasive a set of hopes and fears as the growth of the new and emerging areas of science and technology. During the eighties this fact affected in fundamental ways a whole range of economic activities in agriculture, manufacturing and services. They created new techniques, products and skills and influenced the modes of work and leisure.

There are hopes that these new and emerging areas of science and technology enhance prospects of growth, encourage autonomy and decentralization, improve talents and skills and reduce physical hardship. There are also well founded fears that human values will be sacrificed, nature's processes will be adversely damaged, societal disparities will be widened and individual privacy and freedom of thought will be reduced. These sentiments are based on the observation of the trends and projection of possible scenarios. The ultimate realization of these hopes and fears will be largely influenced by the ways in which societies organize themselves.

It is postulated, however, that the consequences of these emerging areas to developing countries will not necessarily be the same as for developed countries. Therefore developing countries, individually and collectively, have to engage themselves in independent assessments of the beneficial and harmful impacts of the new technology. They have to elucidate the choices on what aspects of the new technology they could actively participate in and for what reasons; which of these technologies they would obtain at any cost and which of them would be ignored; what organizational innovations are required; and what are the adjustments they should be prepared for.

2. TWO CATEGORIES OF NEW TECHNOLOGIES

From the development perspective, two distinct categories of new technologies can be identified. In one category, there are technologies with high R&D intensity whose core aspects of invention and development will, in the foreseeable future, be centered in a handful of countries; and most developing countries including many developed countries could at best participate in the innovative adoption and use of these technologies. Information and communication technologies, space technologies, and materials technologies fall in this category.

In the second category, there are technologies with affordable R&D intensity in which practically every country can hope to participate in every aspect of development and use, albeit on a varying scale and intensity. Biotechnologies and energy technologies lie in these these categories.

Even though the fundamental scientific knowledge required for the technologies in either category may be universally available (though this may also be restricted in the future), what makes this distinction real is the differences in the nature of capital, infrastructure, market conditions and social organization required for the effective development of technologies in these two categories. Given the vast variations in these four factors among developing countries, it would be necessary for every developing country, (and some developed countries as well), to discriminately choose and engage in the most appropriate aspect of the technologies in these two categories.

Among those technologies with high R&D intensity, material's technology is considered as one of the most important areas for the technical innovation. Innovative materials technology will provide the break-through needed to induce new products or new industries. In other words, it will contribute to the innovation of technology and advancement of industry.

3. IMPACT OF MATERIALS ON INDUSTRY AND THE ECONOMY

It is obvious that there is, at present, a growing interest on the part of industries in materials development. Most concerned are, according to the survey conducted in 1981 by the Economic Planning Agency of Japan, the electronics field, particularly "microelectronics", and the development of new materials, followed in order by information processing, recovery and reproduction of spent resources, ocean development, resources and energy development, and atomic energy[1]. As indicated above, new materials together with electronics, are forming the two major development targets of enterprises, bearing out that materials are providing a springboard for new technological innovation. For instance, semiconductor materials determine state-of-the-art and future microelectronics and photonics. The latter particularly depends on the development of comparatively new semiconductors for the newest generation of different electronic devices and sensors. The fast-growing demand for high-purity starting materials provides new market opportunities for the developing countries possessing the necessary raw materials. In short, international trends toward future-oriented new materials development favor electronic materials with new function, fine ceramics, high functional polymers, superconductive materials, crystalline controlled new functional alloys, and composite materials.

To give further details, the typical example of new materials development in the automobile industry, is the development of ceramics for engines. In order to increase engine efficiency, it is indispensable to develop materials that can withstand high temperatures. The replacement of metallic materials by ceramics will not only enable the engine to operate at a much higher temperature than before, but also make cooling systems unnecessary. The resulting higher fuel efficiency may reduce fuel consumption by as much as 30%, but the lack of reliable performance in practical utilization, insufficient processing technology and high price are problems yet to be solved. Another example, steel plate holds absolute superiority as a materials for car body but it is interesting to note the extensive replacement by "plastics", which will eventually decide the future course of this industry. In the United States, the amount of "plastics" used per car is foreseen to increase within the next 10 years by about five times the current rate. In the United States, desperate endeavors are being devoted to reducing car weight so as to increase fuel efficiency. Hence the use of "reinforced plastic" will remain a principal object for development. It is also expected that the early 21st century will witness the introduction of plastic materials reinforced by carbon fiber in lieu of glass fiber. Being lighter than aluminium and harder than iron, more than 9 tons of carbon fiber for the forthcoming models of aircraft are scheduled per aircraft, which is an indication of its mass production[2]. Looking from this point of view, much is expected of composite materials, particularly "advanced composite materials".

The following looks at the relationships between new materials and the energy industry. Although uncertain at the moment, looking ahead, complete elimination of the use of petroleum seems unavoidable. Subsequently, the technological strategy for energy should consider two aspects, namely, energy-savings and substitute energy. To begin with, substitute energy concerns the utilization of solar energy, with the focus, in the long run, directed on solar cells because of the many restrictions on the use of light. To this end, single crystal silicon has been used, but is not cost effective, thereby resulting in the introduction of amorphous silicon. With its manufacturing cost lowered to 1/100 of that of single crystal silicon, there is a possibility that solar cells using amorphous silicon will be able to compete with nuclear power generation, or thermal power generation.

Next is the development and use of alloys for hydrogen-absorption, attractive because of its capability to store hydrogen without a high pressure container. In addition, it is deemed significant to enhance the performance of heat-resistant materials that are necessary for MHD power generation, geothermal power plants, high temperature nuclear reactors, and other related areas. In other words, it is no exaggeration to say that success or failure in developing new energy depends on improving the properties of heat-resistant materials. With respect to the possibility of superconductive materials, development of this sector has started attracting attention since the successful test production of superconductive magnets in the United States in 1961, generating a magnetic field of 70,000 gauss. If alloy or metallic compounds of super-conductivity having no resistance at normal temperatures are found, they will be used in such wide-ranging sectors as MHD generation and nuclear fusion.

The rare and many rare-earth metals now used not only in the manufacture of high-quality steel or magnetic alloys, but also have tremendous prospects for global economic development in connection with superconductivity. Recent advances in the field of high-temperature superconductivity are stimulating commercial development which could have a great impact on many industries. According to some optimistic forecasts, the market of superconductor devices will jump from the present $400 million to $20-34 billion by the end of this century. There are many near-term opportunities to supply raw materials, to synthesize superconducting oxides, to fabricate superconducting powders, films, wires for different applications.

In the future, attention will be devoted toward rare-earth elements and alkaline earth elements which are in limited supply now. Existing separation and refining capacities will not be enough if demand for the new superconductors is to accelerate to the degree now anticipated.

In addition, let's look at influences on the information industry. The term "information age" might sound more abstract, less tangible, than "industrial age"; it is more associated with mental processes than physical ones, but it is based just as firmly on materials science and engineering. True, the information age is heavily dependent upon software. But just as sheet music is lifeless without the hardware of musical instruments, so is software useless without integrated circuits for its implementation. In contrast to the structural, mechanical, and electrical technologies of the industrial age, the information age makes relatively modest demands on raw material resources and energy and is usually benign in its interaction with the environment. On the other hand, communications, computers, and control technologies, the "three Cs" of the information age, are probably the most complex, sophisticated, and demanding technology systems yet devised by mankind. They are rich in invention and added value resulting from intensive, often very large and expensive research and development programs.

It is a well founded prospect advocated by advanced nations that the information industry will replace the automobile industry in the coming generation. As social demands grow, the shift to an information-oriented society is being led principally by computer communications, expedited by the epochmaking progress of IC technology and optical fibers, both of which were derived from the development of new materials. Today's IC is based primarily on a silicon solid element, but sooner or later will most probably be substituted by gallium arsenide, the Josephson element, or other suitable material. Gallium arsenide in particular has the advantage of quick response and a high heat-resistance compared to silicon, which makes it highly promising for the future. Some such new materials are already at the stage of practical use, but will, for the most part, be put to fullest practical utilization in the latter half of 1990's[3].

4. DIRECTIONS IN MATERIALS TECHNOLOGY DEVELOPMENT

Examining the pattern of research and development, it can be classified into three categories; first, assimilation and improvement of imported or existing technologies; second, development of composite technologies or hybrid of main and side technologies; third, creation of innovative high technologies.

Neither developing countries, nor newly industrialized countries, can afford to invest in a technological leap like advanced countries, nor is it necessary to do so. It is not desirable to concentrate, on an all-out approach to develop all sorts of technologies or innovative technologies. Instead, it is advisable that they keep a careful watch over the current status of their own related industries, improve and develop their present technologies one by one, maintain their improved productivity for reducing production costs, and lay the groundwork for research and development activites in order to nurture and accumulate the ability to develop technologies to produce higher grade products. In short, the first pattern of research and development, assimilation and improvement of imported or existing technologies, will still be the norm in developing countries for the next decade.

The second pattern, that of the research of systems development type, aims to develop sophisticated assembling technology in accordance with the needs as well as generation of, new composite technology to increase added value or productivity, making efficient use of existing knowledge and technology. Systems development type research can be subdivided into three parts. The first subject area is plant engineering, for example, various plant designs, optimum equipment and production systems. Next is the systems development type of the assembly industry, including the assembly of computers, aircraft, robots, precision electronic equipments and communication system development. This can create new added value which satisfies new circumstances and demand. The third subject area is the field of total system research for social development, including transportation and traffic network systems, supply and demand systems, systems for the optimum distribution of resources and environmental preservation systems. Furthermore, the current trend of technological development in the process-dependent industry is how side technologies, such as micro-electronics and computers, are combined with main process technologies in order to create new composite technologies.

Developing countries should now turn their eyes to the so-called "systems development type research", which enables current knowledge and technologies in all fields to be integrated under the system pursued.

The third pattern of research and development is innovative, performing research on new products and new technology, steering away from mere imitation. Up to now, we have mainly imported and adopted foreign technology, an unavoidable situation for developing countries entering the stage of technological development. To prepare for a time when the industrial structure will be heightened to compete with advanced countries in world markets, we should develop at least a dozen new products and technologies of our own in certain industrial fields, even if not in all fields.

Materials technology development cannot avoid becoming a field of modern science, even though nearly two centuries have been required for the transition to become complete. Interestingly enough, the purely scientific study of materials emerged in the last century as a result of the curiosity of chemists, physicists, and mineralogists and generated basic questions that have had a major impact on the evolution of the mainstream of modern science, particularly what is now called quantum physics.

The transition of materials research from a primarily empirical, technological endeavor to a truly scientific endeavor achieved its climax in the period following World War II. A large contingent of imaginative and talented young scientists from several disciplines joined in a concerted study of materials with the intention of leaving no area of investigation unexplored. They brought to bear high standards of precision and analysis on both experiment and theory. This movement has continued almost unabated. Whatever the initial impetus for the movement may have been, there is little doubt that it has been sustained at a substantial level in academic, industrial, and governmental laboratories on an international scale in significant part because of its influence on many areas of technology, including electronics, optics, ceramics, metallurgy, and plastics. In fact, much of the advanced exploratory research is now carried on as a normal part of the engineering disciplines[4]. Recent trends for the development of new materials can be viewed from two sides. The first is to seek metals, alloys and new function compounds, and the second is to increase the value added on the existing materials. Development nowadays, from this view point, is represented by three areas: development of new materials, taking advantage of extremity; new applications of materials based on knowledge-intensive composite technology; and creation of new materials by means of crystalline control. In accordance with these directions, the study of future-oriented materials from various angles is actively under way[5].

5. CONCLUDING REMARKS

One main inference from the foregoing discussions on the new and emerging areas of science and technology, is that each country should identify for itself the priority areas which could most advantageously address its particular set of problems under given endowments and constraints. In some new technologies, direct advantages will depend on the extent of a country's minor participation in their development, but the main benefits will come from the innovative use of their findings. In other technologies, the country could launch a full spectrum of the development and use of activities.

Science and technology have made unprecedented progress, especially in the technology based on the science developed during the second half of this century, which has resulted in a globally industrialized society. This progress was accomplished by a marked expansion in research and development activities, in terms of scope as well as depth. Expansion has brought about changes in the organizational pattern of these activities, in the direction of higher specialization and more cooperation. Also, the flow of activities from basic research to commercialization has been segmented into multiple steps. Today, a research and development programme is carried out to attain a predetermined goal; first, by separating the job into different specialities, and then dividing it into a few steps and finally integrating all the elements into one whole unit.

Another characteristic of modern research and development is the large scale of investment in funds, human and other resources, such as those required in atomic energy development, space exploration, ocean development, environmental problems and so on. Modern research and development (R&D) demands careful organization, as well as efficient planning and coordination to cope with the complexity of research problems and the multiplicity of inputs needed to solve them.

To deal with the recent changes in the pattern of R&D, it has become necessary to develop effective cooperative systems that permit integration of subdivided labour carried out by the various subsystems. Systems of cooperation are particularly important in the areas of information exchange, allocation of research manpower and the sharing of research facilities.

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