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## **Materials Technologies and Techno-Economic Development**

### **A study for the German Foundation for International Development (Deutsche Stiftung für Internationale Entwicklung)**

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## Summary

This study was prepared at the request of the German Foundation for International Development (Deutsche Stiftung für Internationale Entwicklung) in order to review the state of the art of materials technologies and their potential for future techno-economic developments.

The importance of materials technologies is immediately obvious from the fact that materials rank together with energy and information as basic resources of mankind. That which distinguishes materials from the other technologies and sciences which are subject of intense current attention is that materials are not an end product in themselves but are needed to permit engineering structures to fulfill their purposes. Demands for improved materials and materials technologies basically spring from the functions required of engineering structures, such as improved performance, integrity and reliability. Materials have an underpinning role, they provide the framework for all industrial sectors in every country and thus they represent essentially an enabling technology.

A review of the state of the art shows that in the industrialized countries there has been a rapid development of "New Materials" and "New Materials Technologies" in recent years. This has led to major new industries, including computers, plastics and synthetic fibres and rubbers and nuclear power. Although there are euphoric claims about the future of new materials such as fine ceramics and composites, their applications lie predominantly in the high technology or value added end of the engineering product market, and a suitable industrial base is needed to support the implantation of such materials and related new technologies.

In considering the possibilities and potentials of materials and materials technologies for developing countries, the following requisites may be named together with the requirement of a "minimum level of technological competence" in order to use their potential chances:

1. The need for local strategies and "appropriate technologies"
2. A concern about the "total materials cycle" in any new development — from the extraction of ores through manufacturing of finished products, use, reuse, recycling and disposal.
3. The consideration of especially suited "new" materials technologies, such as
  - High Strength Low Alloy Steels (HSLA Steels)
  - Fibre Reinforced Structural Composites
  - Powder Metallurgyand the blending with conventional technologies.
4. The necessity of maintenance technologies and strategies
5. The need to mitigate materials deterioration and damage processes like fracture, fatigue, corrosion, wear and biodeterioration through contemporary technologies, as for example surface coatings.
6. The necessity to establish neutral National Institutes for materials testing and quality control.
7. The necessity to establish agreed codes of practice and materials standards and specifications.

*Materials Technologies — Techno-Economic Development — Industrial Development — Developing Countries — Materials Cycle — Materials Testing — Materials Standards — Advance Technology Alert System — Technology Assessment — Cooperation in Materials Technology*



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## 1. Introduction and background

One of the important recommendations that emanated from the 1979 United Nations Conference on Science and Technology for Development was a concern for the implication of new technologies on developing countries and the need for appropriate monitoring of such technologies. As an international mechanism for the early identification and assessment of new scientific and technological developments, an "Advanced Technology Alert System" (ATAS) has been proposed by the United Nations Center for Science and Technology for Development (UNCSTD) and the United Nations Industrial Development Organization (UNIDO). One of the purposes of ATAS is to generate concentrated information on new technologies of special significance to developing countries.

There is a growing interest in materials technologies in Developing Countries because of the potential they carry with regard to better utilisation of material resources, quantitative and qualitative improvements in production, energy conservation and protection of the environment. For lack of knowledge and infrastructure and because of unfavourable general conditions this potential cannot be exploited in most developing countries. It has therefore been recommended that cooperation in Science and Technology be also extended to materials technologies and to promote measures for the improvement of the institutional, personal and material infrastructures in order to enable developing countries to assess new technologies in view of their consequences for production, energy conservation and their environmental impact.

It is believed that Development Cooperation in the field of materials technologies could therefore contribute to a sector specific approach in technology forecasting and assessment by which Science and Technology Policy on the one hand and Development Cooperation on the other would complement each other.

The DSE (Deutsche Stiftung für internationale Entwicklung) which has been dealing with issues of Science and Technology Policy Planning in its programmes since the 1979 UN-Conference on Science and Technology for Development (UNCSTD) has therefore

in consultation with the BMFT (Bundesministerium für Forschung und Technologie - Federal Ministry for Research and Technology) asked the BAM (Bundesanstalt für Materialprüfung - Federal Institute for Materials Testing) to prepare a paper on the area of materials technologies. This paper is meant as a pre-study for an in-depth "ATAS-Bulletin", one of the instruments of ATAS. The paper deals with Materials Technologies under the following aspects:

- Survey of Advanced Materials Technology and Research
- Importance of Materials Technologies for Industrialized and Developing Countries
- Outlook for Future Requisites of Materials Technologies and Development

## 2. Impact of materials and materials technologies

Materials rank together with energy and information as basic resources of mankind. Thus, materials and materials technologies play a key role in industry, economy and society of all countries. Broadly speaking, the term "material" denotes physical matter which is used to construct things - machines, devices, habitations and other objects required by Man in the course of everyday life. This covers a wide spectrum of materials types and usages. In Table 1 we list the major classes of materials, and give some examples, noting the principal properties and some applications.

That which distinguishes materials from the other technologies and sciences which are the subject of intense current attention is that materials are not an end product in themselves - they are needed to permit engineering structures to fulfill their functions. In this sense then, materials have an underpinning role, they provide the framework for all industrial sectors, including e.g. mechanical and chemical engineering, and thus they represent essentially an enabling technology.

In 1979 the US National Academy of Sciences in its "Five-Year Outlook on Science and Technology" has reviewed some of the major

materials developments as being those likely to have a major impact to society out to the turn of the century /1/. The review includes the following materials and materials-related developments as characteristic examples:

- Synthetic Polymers
- High-performance resin-and metal-matrix composites
- Surface technologies (e.g. LASER treatments)
- Silicon nitride and silicon carbide ceramics
- High strength low alloy steels
- Rapidly-solidified superalloys
- Single-crystal machinery components (e.g. turbine blades)
- Fibre optic transmissions
- Very large scale, integrated-circuit silicon chips
- Improved high-capacity computer memories ("magnetic bubble memories")
- Semiconductor integrated detectors
- Powder metallurgy techniques
- Precision casting technologies ("net shape fabrication")
- Computer-aided design and manufacturing (CAD, CAM)

If it is tried to review systematically the state of the art of contemporary materials technology, the major developments of materials in recent years can be discussed under the following headings:

- I. Metals and Alloys
- II. Inorganic Materials; Ceramics
- III. Organic Materials; Polymers
- IV. Composite Materials
- V. Renewable Materials
- VI. Energy-related Materials
- VII. Information-related Materials
- VIII. Materials Processing and Manufacturing
- IX. Conservation, Recycling, Substitution.

Of course, such a division is to some degree artificial and by no means all inclusive and the various views overlap considerably. However, the classification provides a convenient basis for the review of the state of the art of contemporary materials science and technology, as given in the APPENDIX.

### 3. Importance of materials technologies for industrialized countries

From the consideration of the main classes of advanced materials as given in the APPENDIX it is obvious that materials technologies are of fundamental importance for industry and economy of all industrialized countries. The widespread use of materials in industrial activity has resulted in a concern over their availability and given rise to studies about materials policy issues. In 1974 the COSMAT Report "Materials and Man's Needs" compiled by the Committee on the Survey of Materials Science and Engineering was published by the US National Academy of Sciences /2/. The importance of materials was illustrated by the finding that about 1/5 of the US Gross National Product originated from the extracting, refining, processing and forming of materials into finished goods and that manufacturing employment related to materials was just over 21 percent of the total US employment. By evaluating information from approximately 1000 questionnaires which were sent out in North America to many different institutions dealing with materials from basic resources to finished products, the importance of materials in the following areas of national impact was considered:

- Housing and other constructions
- Consumer goods
- Production equipment
- Transportation equipment
- Communications, computers, control
- Energy
- Environmental quality
- Health services.

The materials which are relevant to the areas of impact with a high degree of priority for research and engineering are listed in Table 2. The compilation underlines again the underpinning role of materials technologies for society.

The further development of "New Materials" (in connection with other "New Technologies", like microelectronics or advanced CAM-systems) may have some important implications on the industrial systems in the industrialized countries /3/:



- The intellectual and financial efforts for the development and design phase by the companies increase considerably.
- The connections between the phases of development, design and production of final products are increasingly tighter. This means that the product cycles are shorter and the development and design phase is often longer than the life cycle of the pertinent products.
- The interdependencies between industrial production systems and product-oriented services are increasing. This means that complex products can only be sold competitively at the international market if industrial product systems are coupled with efficient product-oriented services.
- The increasing interindustrial interdependencies in advanced industrial systems will have important effects on the industrial organizational structures. Depending on the type of products, this will lead both to processes of concentration and of deconcentration.

The economic and social impacts of the technological process in "strategic industries" in the industrialized countries cannot yet sufficiently be estimated. The effect of new technologies on economical growth and employment may be different in the three leading industrial areas, namely the USA, Western Europe and Japan. It has been estimated /3/ that in the USA only 13% of the 105 Million employees are working in "high-tech" industries, which are only 14 Million employees. The main increases in employment have been reached in recent times in the areas of low-wages services whereas the number of "high-tech"-employees has only changed very little. For the Federal Republic of Germany similar relations seem to be valid. It may be assumed that only 4 Million employees out of the total of 26 Million employees are working in the high technology area. On the other hand in Japan where the so-called new technologies have the broadest effect, a very low unemployment rate is observed. However, this must also be seen in connection with other factors like the characteristic industrial organizations and the social structures of Japanese companies.

These brief considerations indicate that the connections between materials technologies, industrial structures and economy are by no means simple and need thorough analyses which consider the influences of numerous technological, economical and social factors. In a simplistic view three fundamental changes are to be observed /4/:

- For basic materials industries, growth of output in pounds is not a desirable main criterium any more.
- A steady but accelerated trend towards adding more know-how in the use of materials and their properties
- Last but not least the demand by people for better quality for life will be the main driving force in industry's activities. This term "quality of life" comprises not only environmental protection but in general providing new and more sophisticated products and services.

#### 4. Importance of materials technologies for developing countries

##### 4.1 General considerations

Although there is no standard definition of a developing country, it is a country that falls below the standards by which "development" in some sense is measured. One typical difference between the industrial countries and the developing countries is obvious from a look at the exports of the developing countries. Table 3 shows the well-known fact that the export of most developing countries depend crucially on a few natural goods and raw materials rather than on industrial products.

Another interesting comparison concerns the consumption of materials in the various countries and possible correlations with economic growth and the gross national product (GNP). Clearly the highest consumption of materials is in the industrialized countries. Figure 1 illustrates in a highly simplified manner that the industrial countries have gone through a prolonged period of rather steady growth in per capita consumption of materials /4/. For example, in most of the industrialized coun-

tries, between 1950 and 1974 the per capita consumption of steel increased annually by 4 to 6 % and that of aluminium by 8 to 10 % to just quote two material types. In projections to the year 2000 the industrialized countries high share in materials consumption will continue but will undergo percentage-wise decreases as developing countries and middle income countries grow in relative economic importance. The schematic drawing in Figure 1 indicates that the developing countries are right now entering an increased growth rate in per capita consumption of materials.

There is a general relationship between demand for material resources and GNP. In developing countries, materials consumption tends to increase more rapidly than GNP. In Africa, for example, the growth rate of aluminium demand has remained relatively constant at around 12 % per year for more than 20 years, and during the same time period GNP has been increasing at around 3 %. In other words, aluminium consumption is increasing at a rate four times that of GNP in Africa /4/. It appears that new material developments involve chances as well as risks for the developing countries. Depending on new materials development demand may be reduced for some of the traditional materials, such as steel, copper and aluminium, putting strength on existing industries that already suffer from world excess capacity. In addition the substitution of new materials for traditional metals will tend to depress earnings of the ore producers around the world. The effect on demand for the more exotic materials is difficult to judge. As tailored alloys replace standard metals, demand for the alloying components will rise. At the same time new materials may be found to substitute for the special properties of some of these alloying components. A further important contribution of new materials will be toward conserving energy. They will do this partly by weight reducing substitution for heavier materials such as steel and copper of moving vehicles such as autos, trucks and airplanes, thereby reducing fuel requirements per ton of payload. They will conserve energy partly also in the production process where less energy will often be required to make a new substitute product to perform a specific task (f.e. laminated graphite fibre as a substitute for aluminium on the skin of an aircraft).

Although, many of the advances in new materials generally occur in the industrialized countries which have large research and de-

velopment programs in new materials and a ready market for application, the results of the advances will reach the developing countries through changes in the pattern of new material trade and changes in usage of materials in their economies. In addition developing countries may develop their own new materials and uses, e.g. composites, suitable to their resource and domains. However, the diversity of conditions in developing countries and the endowment of raw materials will require different approaches to be evolved by each country. The question "which material technology is most appropriate" cannot be answered through comprehensive catalogues or criteria in a general manner. Instead this question has to be considered and answered individually in any single case. It appears that the following questions must be answered before and during planning basic materials industries /4/:

- Where is the natural resource located?
- By what method can it be extracted?
- How and where will it be processed?
- What are the impacts on natural environment?
- What are the energy implications?
- What will it cost?
- What is its commercial value at current and likely future prices?
- What are the export possibilities?
- What impact on imports can be expected?
- What social-economic effects are to be anticipated?

#### 4.2 The example of South Korea

It has been emphasized above that owing to the diversity of materials and developing country conditions a selective approach needs to be adopted. Each country will have to identify specific materials and the criteria on the basis of which policy action should be taken. In considering the example of South Korea it can be illustrated how an "advanced developing country" has tried to use "new science and technology" for its developing process. South Korea as a medium-sized developing country with minor resources started as an "early imitator" and put in a long lasting period considerable effort to improve education in all areas and to lay the foundation for a "scientific-technological infrastructure". The developing strategy of South Korea aimed to de-

velop an industrial production apparatus which concentrates on technology-intensive product lines. Whereas the importance of raw materials and labor-intensive industries (steel-industry, chemical base industries, textile-industries) will decrease, other industries like electronic industries, mechanical engineering and automobile-industries will grow more than average. In addition the sector of product-oriented services will be developed further. The main building blocks of the broadly designed technological development strategy include the following components:

- The use of "economies of scope" (synergistic effects) consisting of a simultaneous development of strategic industrial sectors (electronics, mechanical engineering, automobile industry) and product-oriented services (communications, banking, insurances, contract research, marketing organizations)
- Selected, goal-oriented import of "best practice technologies"
- Rapid development of R&D-departments in large companies
- Completion and strengthening of industry-oriented research institutions
- Formation of research activities in important industry-strategic areas like semiconductor development, flexible fabrication systems
- Enlistment of top South Korean managers with longlasting experience in top positions in American companies and research institutions
- Preparation of "Venture Capital"
- Activities on R&D-incentive systems
- Cautious opening against foreign investments
- Continuous governmental examination of R&D activities of industry and economy
- Intensive consultation processes between government, industry and research institutes

The example of South Korea illustrates the comprehensive efforts necessary to use and to apply advanced technologies in a developing country. Again, each country has to identify its own criteria on the basis of which techno-economic strategies can be developed. In any case it appears necessary that any developing country must develop a "minimum level of technological competence" in order to use the potential chances of new advanced technologies.

## 5. Requisites of materials technologies for developing countries

Having discussed the state of the art of advanced materials technologies and their importance for industrialized and developing countries, considerations of requisites of materials technologies for developing countries should be made. Because of the immense broad spectrum of advanced materials and materials technologies and the complexities of industrial and economic structures only some general remarks can be made in a brief manner.

### 5.1 The need for local strategies and appropriate technologies

At the outset we should emphasize again that owing to the diversity of materials and developing country conditions a selective approach needs to be adopted. Each country will have to identify specific materials and the criteria on the basis of which policy action should be taken. The criteria would cover and be guided by such factors as the country's imports and exports, the possible local use of substitute materials, the energy implications of the new materials and the local conditions, skills and facilities to use them. Based on thorough studies in the various local areas the most suited "appropriate technologies" should be identified.

As we consider the most suited kinds of technologies and the form of its applications in the developing world we may risk an emotional response to the expression "appropriate technology". To the developing countries this may be misunderstood as describing the old and obsolete processes which can no longer be used actively in the industrialized countries. However, the term "appropriate technology" properly describes that technology which

will contribute maximum benefits to the recipient local area. To foist on a developing country the most sophisticated technology were not appropriate to the prevailing conditions, may often be tragic and a serious disservice to that country.

Instead it should be attempted to blend and to integrate emerging technologies and traditional technologies. This approach has been emphasized in recent years by various experts and organizations. For example, the United Nations Advisory Committee on Science and Technology for Development (ACSTD) /5/ and the International Labour Office /6/ have considered possible areas for an integration of emerging and traditional technologies, including the following material-oriented sectors:

- New construction materials for developing countries
- Materials for rural housing
- Integration of old and new technologies in the textile industry
- New photovoltaic techniques for farm applications and power supply for villages.

In a thorough study the most suited materials-oriented areas for this approach should be discussed comprehensively.

## 5.2 Consideration of the total materials cycle

If in a certain local area the adoption or creation of "appropriate technologies" or "advanced technologies" is considered, it is imperative that also the total materials cycle must be considered as illustrated in a simplified manner in Figure 2 which is taken from Reference /2/.

All materials move in a "total materials cycle". From the earth and its atmosphere man takes ores, hydrocarbons, wood, oxygen and other substances in crude form and extracts, refines, purifies and converts them into simple metals, chemicals and other basic raw materials. He modifies these raw materials to alloys, ceramics, electronic materials, polymers, composites and other compositions to meet performance requirements. From the modified materials he makes shapes or parts for assembly into products. The product, when its useful life is ended, returns to the earth

or the atmosphere as waste or it may be dismantled to recover basic materials that reenter the cycle.

The activities of materials industries should be seen with respect to the entire materials cycle. Looking at the many different stations of this cycle, it is immediately evident that only a multidisciplinary approach could deal with all the technological and market oriented questions related to materials industries. From the raw material to the finished product and its discard or recycling there are interactions with the following key elements:

- Energy intensity of processes and products
- Environmental impacts
- Local labor and other social structures
- Innovation and technological leadership
- Free market forces versus national materials policy.

The total materials cycle is not only a guide for establishing new materials industries but also a means for assessing the influence of changes in materials technologies by new "advanced" techniques. It must be born in mind that any adaption of "new technologies" may disturbe severely the materials cycle of existing traditional local industries.

### 5.3 Discussion of advanced material technologies possibly suited for developing countries

There is at present an intense discussion on the influence of new materials technologies to developing countries which may range from the impact of new technologies in the building and construction industries to the impact of optical fibre-glass technology on the economies of copper producing countries. Under the auspices of the United Nations Industrial Development Organization (UNIDO) the implications of new materials and technology for developing countries were considered /7/. Because the materials field is so broad and there are so many advances that could be considered, the following criteria for the selection of materials technologies suitable for developing countries have been suggested /8/:



- A. The technical advance is clearly established and is not a matter of hope or near promise
- B. The topic is one of broad scope, rather than a narrow product or process
- C. The new development should represent an industrial opportunity for the developing countries.
- D. The choice should be limited to an important few.

As a result of this screening process the following materials technologies were selected because they appear to be especially important to developing countries /8/:

- High Strength Low Alloy Steels (HSLA Steels)

HSLA Steels are a new element of the steel market with high growth prospects. Therefore developing countries producing these quality steels could find a developing market. These new steels are a higher value product than conventional carbon grades and therefore represent better use of the capital investment. This is an important factor for developing countries which are at an early stage of entry into steel making. However, before trying to establish HSLA Technologies, proper technological and economical studies by considering the arguments discussed in Section 5.1 and 5.2 should be made.

- Fibre Reinforced Structural Composites

Plastic materials are now well established as substitutes for a wide range of traditional materials such as metals and timber. The use of fillers in plastic materials is of interest to developing countries because it reduces the cost of the material and also requires less petrochemical base stock. A number of inexpensive fibre reinforcements and readily available such as basalt fibres, sisal fibres and bamboo, provide a cheap but strong structural material for many applications in developing countries. Another advantage of composite material technology is that it can be fabricated by hand, lay up and press moulding, which are suitable for small and moderate size markets.

## ● Powder Metallurgy

Powder Metallurgy is another area which has relevance to developing countries because it is a highly flexible technology and has in certain applications lower costs than conventional fusion metallurgy. One such application which may be particularly relevant to developing countries is the rolling of metal powders to produce sheet. Another major advantage of this technology for developing countries with limited capital availability is the fact that the powder metallurgy industry can be introduced on an incremental basis.

In addition, the importance of other advanced materials technologies (as reviewed in the APPENDIX) for individual developing countries may be considered with the above screening criteria A to D and the additional requisites discussed in Sections 5.1 and 5.2.

### 5.4 The necessity of maintenance technologies and strategies

In addition to possible attempts to introduce new advanced materials as "hardware technologies" to developing countries as outlined in the foregoing section, more attention must also be paid to beneficial "software technologies", like maintenance technologies. Whereas "maintenance" is often not considered to be part of the main stream of industrial activities and involves sometimes unattractive impressions, it is nevertheless one of the most important necessities for industry both in developed and in developing countries /9/. This is obvious from the following figures and examples /10/:

- In industrialized countries a considerable part of the gross national product (GNP) is needed for maintenance, as for example
  - 12,00% of GNP in Japan
  - 12,00% of GNP in Austria
  - 10,27% of GNP in the Fed.Rep. of Germany

In the US steel industry, the portion of maintenance costs sum up to \$ 100 within the price of about \$ 550 for one ton of steel.

- In developing countries inappropriate maintenance is often the main obstacle (or fault or thoughtlessness) which hinders or negatively influences all industrial sectors, including the materials industries. For example, a steel plant in Algeria with a staff of 17 000 people which has been designed for an annual output of 2 Million tons of steel fabricates only 300 000 tons of steel per year. The plant registers standstill periods of about 65 to 70% which are mainly due to inappropriate maintenance. For similar reasons, in India another plant which has been designed for an annual output of 40 000 tons of steel tubes supplies only 12 000 to 15 000 tons per year. There is a 60% diminution of the capacity of the plant.

These few figures and examples illustrate the great importance of maintenance technologies. There appears to be an urgent need for improved maintenance of the materials-oriented industries. Attempts to improve maintenance should include the following aspects:

- Consideration of the requirements of the local industries
- A better concern for the requirements of improved maintenance in all levels of the industrial hierarchy
- Improved education for the tasks of maintenance technology.

Because of its broad scope, the appropriate strategies of improved maintenance technologies should be discussed in a separate study.

#### 5.5 Application of advanced methods to mitigate materials deterioration processes

Whereas it is imperative that every developing country must adopt a selective approach for the possible application of improved material and maintenance technologies to their individual techno-economic situation, there appears to be one generally applicable way for materials-related improvements: the mitigation of materials deterioration processes by advanced materials technological means. Several studies have shown that the economic losses in the industrialized countries by materials deterioration processes sum up to about 4 to 6 % of the gross national product /11/. The main materials deterioration processes include

- fracture
- fatigue
- corrosion
- wear
- biodeterioration

The attempts to mitigate these material deterioration processes are not only of great economic importance but lead also to improved quality, reliability, safety and function capability of industrial products. Clearly, the results of these attempts will benefit all branches of industry not only in industrialized countries but also in the developing countries.

As an important means to mitigate materials deterioration processes the importance of SURFACE ENGINEERING AND TECHNOLOGY in the various branches of industry has increased in recent years mainly for the following reasons:

- Improvement of the service life and protection of components from materials deterioration processes named above
- The need for rational use of material, cost-effective production and economic energy consumption while at the same time meeting the obligations and requirements of environmental protection
- The need to create "functional" engineering surfaces by surface treatments, specific to the application in question, carried out on inexpensive and readily available basic raw materials.

There are many advanced techniques like galvanic and chemical coatings, thermo-diffusion coatings, physical and chemical vapor deposition (PVD, CVD) which can be applied to mitigate materials deterioration processes and to improve the function, quality and reliability of technical products of all kinds. The applicability of these advanced technologies to developing countries should be seriously considered.

#### 5.6 Establishment of National Institutions for materials testing and quality control

As an important prerequisite for the industrial development and the possible adoption of advanced materials technologies in

developing countries the establishment of neutral national institutes for materials testing and quality control is strongly suggested. Historically such institutes have played an important role in the industrialization process of today's industrialized countries and are still often leading centers of advanced materials research and development. In developing countries the establishment of such institutions may be a focal point for improving the materials-related technologies in the pertinent country. The requirements for institutions for materials testing and quality control in developing countries should be specified in a separate study.

#### 5.7 Establishment of codes of practice and materials standards

For the proper use and application of technical products of all kinds the existence of appropriate codes of practice and standards is another imperative. In close connections with the above mentioned national centers for materials testing and quality control (see Section 5.6) appropriate institutions for standardization in the developing countries should be established. Also here the requirements for those institutions should be specified in a separate study.



## APPENDIX

### Advanced materials technology and research - State of the art

#### I. Metals and alloys

In basic metals such as iron and steel, aluminium and copper incremental improvements in specific properties are expected rather than striking advances on a broad front /1/. Newer metals whose uses have grown during the passed three decades include the reactive metals - titanium, zirconium, and hafnium - and the refractory metals - niobium, tantalum, molybdenum, and tungsten. Titanium, which has some favourable properties like high strength, low specific weight, excellent corrosion resistance, is of particular importance in aircraft constructions. It will come also to be used in other applications: chemical plants, heat exchangers, electrodes, marine technology, power plants (nuclear, coal-fired and geothermal). As further characteristic examples of the developments of metals and alloys in recent years, the following areas can be mentioned:

##### ● Superalloys

Alloys based on nickel, cobalt or iron and intended for service above 500°C are frequently termed superalloys. They are used for turbines and compressor discs, turbine vanes and blades and other hot components. The use of high-temperature nickel and cobalt alloys for turbine blades with special anisotropic grain structures obtained by controlled solidification will make it possible to increase the operating temperature of gas turbines beyond 950°C and thereby to increase the thrust/weight ratio by 15%. The use of directionally solidified materials and single-crystal components will increase the durability of equipments like turbines and may increase peak operating temperatures and thus efficiency.

##### ● High Strength Low Alloy Steels (HSLA Steels)

HSLA steels comprise a relatively new class of engineering materials. They are low-carbon steels, modified with a small addition of one of the following elements: vanadium, niobium or titanium. Since the addition of one (or a combination) of these three elements is usually less than

0.1%, the term microalloying is frequently applied to this class of steels. Compared to common carbon steels the HSLA steels exhibit a 2 to 3 times higher yield strength (ca. 350 to 500 MPa). In addition to strength the new steels exhibit an attractive balance of engineering properties such as ductility, toughness and weldability. Low-carbon microalloyed HSLA steels are being produced as bars, sheets, plates, structural shapes and tubular products. In addition in medium and high-carbon steel grades small amounts of vanadium were found useful in a production of cold drawn bars forging steels and rail steels, leading to great reduction in the general steel construction industry, fabricating and shipbuilding industries /12/.

- Glassy metals

These materials consist of metals like iron, cobalt and nickel alloyed with elements such as phosphorus, silicon and boron and are solidified in noncrystalline or amorphous form like glass by very fast cooling -  $10^5$  to  $10^6$  °C /sec. Advantages of these materials: considerably improved magnetic and electrical properties compared with crystalline metals, higher mechanical strength and corrosion resistance. They can be used to advantage in the following applications: cores for electrical windings and transformers, television and magnetic tape technology. (It has been estimated that the replacement of conventional transformer cores would mean a potential saving of electrical energy losses in the USA equivalent to 6 Million barrels, i.e. approximately  $10^9$  liters of oil per year /1/).

## II. Inorganic materials; ceramics

Ceramics may be broadly defined as inorganic non metallic materials processed or consolidated at high temperatures. Several new classes of "high-performance ceramics" (base: high-purity oxides, such as aluminium oxide and synthetic carbides, nitrides, borides, silicates and phosphates), with special advanced properties are currently being investigated at materials research laboratories. As illustrated in a highly simplified manner in Figure 3, it is attempted to create ceramic materials with specific homogenous microstructures in order to improve the technological properties



of those materials /13/. The technical advantages of ceramics are besides other things: raw materials readily available, high chemical and thermal stability, extremely high hardness values. The industrial applications range from electrical insulation components, cutting and forming tools, bearing materials, nozzles and chemical pumps through biotechnical materials such as artificial hip joints to housings for microelectronics chips. Non-oxidizing thermally stable materials, such as silicon nitride, are suitable in principle for use both in Diesel engines and gas turbines and in high-performance cutting tools. A systematic classification of high-performance ceramics by function is provided in Table 4. It is estimated that by 1990 the value of ceramics used by the automotive industry in Japan will be US\$ 1500 Million for cars and US\$ 1350 Million for other vehicles. If the present very intensive research effort on engines based on ceramics will be successful, the figures may be even higher /14/.

### III. Organic materials; polymers

A broad variety of useful plastics, elastomers and other polymers have become commercial products in recent years. They are at present the fastest growing class of materials /1/. Trends in polymers are at the forefront of future technologies. Commercial developments over the passed two decades include:

- Polyamide fibres with strength and modulus properties superior to many materials commercially available today
- Temperature resistant aromatic polymers which will displace many strategic metals for elevated temperature applications
- Electronically active polymers with electrical conductivities close to those of conventional metals
- Improved thermoplastic resins suitable for stamping out high-production-rate, fibre-reinforced composite parts
- Polymer blends, alloys and multi-component structures with optimum combinations of properties.

There is a continuous interest to develop high performance polymer materials which are light in weight but as strong as metal. As illustrated in a highly simplified manner in Figure 4, the development of these materials is considered possible through the technique of high crystallization. They are expected to replace structural materials made of aluminium or steel. Thus, the areas of construction (e.g. thermal insulation, seeding) packaging and containers will remain major markets for plastics in the years ahead. In addition the automobile industry is a growing market for plastics which in part will be weight-saving replacements for steel. For example, bumper systems employing reaction-injection molded urethane fascias are already familiar and new bumper systems employing injection-molded blends of polycarbonate and polyester to form a "toughened" polymer alloy are currently being introduced in the United States and Europe. These new bumper systems will offer an eight pound weight savings over an unadorned high-strength-steel bumper. Other applications of advanced polymers to automobiles will include the tires, structural components, panelling, upholstery, trim, battery, electrical distribution system and electrical sensors and displays.

#### IV. Composite materials

Composite materials are made up of two or more component materials, each individual and separate in itself but intimately interconnected. Composite materials generally fall into the following main categories:

- Fibre-reinforced materials
- Surface-coated materials
- Layered materials
- Particel composite materials.

The materials for the matrix and the constituents (fibres, coatings, layers, particles) may consist of any of the main types of materials (metals, ceramics, plastics, cement, glass, rubber). A simplified picture of some features of conventional materials and advanced composite materials is given in Figure 5.

Composite materials are always used in the pursuit of a specific technological aim: to improve performance compared with the use

of single-component materials in respect of resistance to corrosion or wear, appearance of optical characteristics, thermo-mechanical strength, heat or noise insulation or weight reduction for energy-saving purposes. The quest for new materials with higher strength and stiffness relative to their density for transportation systems has led to increasing use of composite materials consisting of reinforcing fibres of carbon polymers, metals and ceramics embedded in matrices of polymer resins, metals and ceramics. Larger percentages of the structural weight of airframes for aircrafts are now being fabricated from graphite-plastics. Furthermore, these composites are finding increasing use for helicopter rotors and propellers. Applications of composite materials in cars, trucks and off-highway equipment are also increasing considerably and will continue to expand as processes yield products with more reproducible properties and as designers devise more effective joining methods.

#### V. Renewable materials

Renewable resources are a potentially attractive source of materials. There is some renewed and steadily increasing interest in the development and the fabrication of new types of engineering or functional materials from resources like wood and wild plants, including for example guayule, a source of rubber and jobjoba, a source of lubricating oil /1/.

In the field of wood-based materials some developments have been performed in recent years in order to improve the technological properties (e.g. strength properties, durability) of these materials. Further, attempts have been made to use minor-valued resources, like bio-mass (e.g. leaves, bark) as substitute for timber. It has been shown for example that about 20% of the wood-content of particle boards can be substituted by replacing wood particles in the intermediate layer of particle boards by bio-mass without changing the strength properties /15/. Also the fabrication of plywood has been rationalized by the "ComPly"-technique. In this technique only the outer part of timber is peeled and the remaining is chipped. This material together with glue is pressed between veneer to form a composite material. Other technological improvements have been obtained with the "MDF-boards" (medium density fibre boards). A further interesting

development concerns the so-called OSB-technique (oriented structural board) which leads to particle boards of high strength by using oriented layers of wood particles in the particle board fabrication process /16/.

## VI. Energy-related materials

In the coming years an extensive R&D effort in materials technology for energy systems is to be expected in order to:

- improve the efficiency of conventional energy systems
- acquire the technological base necessary to exploit the fossile resources (gas, oil, coal)
- continue to improve the efficiency and safety of existing light water reactor systems
- develop non-conventional and renewable sources of energy.

Considering the basic classes of materials (see sections I to III) there appear to be important needs and opportunities for new, advanced materials.

### ● Metals and Alloys

Modified austenitic stainless steels may be optimized for use in wall structures for magnetically-confined fusion systems. Alternate alloy developments to search for better combinations of temperature capability and radiation resistance may include FeCr-Ni super alloys, reactive and refractory metals and alloys, and new concepts such as Fe- and Co-based long-range ordered alloys, rapidly-solidified alloys and graded materials. Other efforts on metal alloys for energy systems may focus in the future on

- structural steels with reduced susceptibility to hydrogen embrittlement and attack for hydrogen storage systems and large pressure vessels for coal conversion systems
- improved wear resistant materials and coatings for coal conversion systems, coal slurry pipelines, geothermal drilling tools and direct-cycle gas turbine components and heat exchangers

- alloys which can withstand the corrosive attack of coal liquids; magnetohydrodynamic seed recovery process; vanadium-, sulfur- and sodium-containing petroleum fuels; geothermal fluids; and molten-salt heat transfer and storage media fluids for solar conversion systems.

- Ceramics

There appear to be some interesting developments in high-performance ceramics for energy systems in the future. For example, in addition to advanced heat engine applications discussed above (see Section II) a variety of insulators and structural ceramics will be required in advanced energy systems like fusion reactors. Other important applications for high-performance ceramics may include:

- ceramics as separators for fuel cells and sodium-sulfur batteries
- ceramics for electric-resistance-charged heat storage units
- silicon-based ceramic recuperators and hot-section components for high-temperature stationary gas turbines
- cermets for high-performance selective solar absorbers
- Refractory liners for coal gasifiers
- magneto-hydrodynamic electrodes, interelectrode insulators and air-preheater refractories
- ceramic and intermetallic protective and thermal barrier coatings for gas turbine and Diesel engine combustion zone components.

- Polymers

One extensive application of polymers in energy systems over the next decade is expected to be for active and passive solar collector systems. Special polymer films will be used as metallized reflectors, selective adsorbing laminated sheets, Fresnel

lenses and protective polymer coatings. Active polymers will also find uses as electrolytes in production by the electrolysis and photolysis of water and as low-cost photovoltaic semiconductors and optical circuit components. Other structural applications of polymers and polymer composites will be as flywheel rotors for mechanical energy storage, gas centrifuge rotors for uranium isotope separation, coatings and containment shells for laser and particle-beam targets for inertially-confined fusion, polymer concrete pipe used in the completion of geothermal wells, and as fluorocarbon elastomers for seals.

In addition to metals, ceramics and polymers also the following class of materials is of great importance for energy systems:

- Semiconductors

Efforts will continue to find methods for producing low-cost, highly-efficient semiconductors solar cells for converting sunlight directly to electricity through photovoltaic effects. Continued process improvements and cost reductions introducing thin-film, polycrystalline, silicon cells on low-cost substrates with efficiencies greater than 10% can be expected. This will make solar cells of amorphous silicon economically viable as an energy source for portable electronic devices. However, solar cells are not expected to be a significant source of energy production in this century.

## VII. Information-related materials

Materials play a crucial role in contemporary and future information technology as illustrated briefly in the following examples /1/:

- Transistor and computer materials

Electronic is probably the most rapidly accelerating area in technology today and silicon in the near term will remain the most emphasized electronic material. Due to the ability to control the composition, structure and processing of silicon-based components, the number of electronic components on a single integrated, circuit silicon chip has doubled and

the cost per component has fallen by nearly half annually for about two decades. A strong effort is under way in the development of new lithographic techniques employing electron beams and X-rays and of dry processing techniques such as plasma-etching and laser-annealed ionimplantation. In addition a technology is rapidly being developed for producing computer memory using magnetic substances such as gadolinium-iron-garnet ("bubble-memories"). These bubble-memories store information at very high density as microscopic magneticized domains.

- Fibre optics

Glass and quartz fibres have been developed through which information in the form of light signals can be transmitted over several miles. At present optical communication systems are built around discrete optical components. The source is driven by electronics and the optical signal goes directly from the fibre into a detector which converts it back into an electronic signal. Communication by fibre-optic transmission is well advanced and will see major growth in the next years.

- Electronic displays

Electronic displays will continue to replace most of the mechanical devices used now to depict letters and numbers in cash registers, home appliances, instrument panels and other equipment. Such displays will use light-emitting diodes, liquid crystals and gas-discharge devices and will be driven by digital circuitry. Current R&D-efforts concern the performance of the materials which currently limit the utility of these devices.

## VIII. Materials processing and manufacturing

Materials processing is, broadly speaking, the conversion of raw materials into intermediate or finished products with useful shapes and properties. In the past 50 years productivity and product quality in basic materials industries like the metals industries have been considerably improved by important engineering advances in materials processes and manufacturing. Examples are continuous rolling of strip, automatic gauge (thickness), con-



trol, electronic inspection of tubes and computer control of rolling mills. Further advances are due to the development of the numerically controlled machine tool in the 1950's and the evolution of computer-aided manufacturing techniques. In full-scale use computer-aided manufacturing (CAM) will be capable of providing: computer generation of the optimized production plans including selection of processes, equipment, tooling, operating conditions etc. It further leads to optimized production control, namely the dynamic scheduling of the work, maximizing and balancing the use of the manufacturing equipment, minimizing the time that parts and process lie waiting to be worked on etc. Finally, it helps to realize the automated machining of the parts by numerical control of machine tools. Numerical control, design data are combined with manufacturing data to produce a control program. The program is then used via punched tape or small computer, to control one or more machine tools that produce the finished parts from raw stock.

In addition, the last decades have provided many notable advances in near-net shape fabrication methods which greatly reduce or in some cases eliminate the need for final machining or grinding operations. For example, in sophisticated production techniques turbine blades are now being produced by single crystal castings and complex shapes are being commercially produced by one-step superplastic forging of powdered-metal billets. Advances in cutting tool materials are fulfilling needs for higher tool speeds and material removal rates. The availability of advanced ceramic, ceramic-metallic compacts, intermetallic compounds and ceramic coatings has been a key enabling factor in contemporary manufacturing and materials processing technologies. Further advances in materials processes include

- laser and electron-beam surface heat treatment
- plasma processing
- photon-activated chemical reactions
- dynamic compaction of ceramic and metal powders
- microjoining
- diffusion bonding
- molecular-beam epitaxy
- rapid solidification
- high pressure synthesis



- hot-isostatic pressing
- convection-free crystal growth
- microencapsulation.

## IX. Conservation, Recycling, Substitution

One general aspect of contemporary materials technology concerns the optimum use and application of resources and products. Thus, the topics of conservation, recycling and substitution have been attracted considerable interest in recent years.

### ● Conservation

It has been estimated that in the highly industrialized countries enormous losses which sum up to about 4 to 6 % of the national product are due to materials deterioration processes. These processes influence the quality, reliability, safety and functional capability of industrial products of all kinds. Knowledge of the mechanisms of deterioration is an essential precondition for the improvement of materials and components with the aim of assuring their quality and function. The materials deterioration processes include

- fracture
- fatigue
- corrosion
- wear
- biodeterioration

It is attempted to mitigate these materials deterioration processes by applying new techniques like fracture mechanics and surface science and technology.

### ● Recycling

Recycling of products offers market potential for conserving materials, recovering the energy invested regionally in manufacturing the products, and reducing the pollution resulting from manufacturing. Whereas some progress has been obtained in the recycling of metals (e.g. aluminium cans) a most important problem requiring research and development during the next

years is the recycling of plastic scrap. Processes are needed to separate waste plastics satisfactorily for reuse or conversion to chemical materials or alternatively to convert them pyrolytically (at high temperature without burning) to a petroleum equivalent for use as fuel.

● Substitution

Substitution of one material for another has been motivated by cost reduction, specific functional advantages, or supply considerations. In general, substitution tends to be an evolutionary process. It results not only from the advent of new materials, but also from improvements and tailoring of older materials for specific uses. Examples for the R&D efforts to the substitution of materials, e.g. substitution of metals by ceramics and plastics or substitution of wood by bio-mass, have been discussed above.

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Table 1: Materials used by Society

Classes	Some Examples	Principal properties of characteristics	Examples of Usage
Metals & Alloys	Steels, super-alloys, light alloys	Strength, toughness	Automobiles, aircraft, pressure vessels
Ceramics & Cermets	Alumina, silicon nitride, metal carbides	Temperature & corrosion resistance, high hardness	Furnace refractories, engine components
Plastics & Elastomers	Polymers, rubbers, polyurethanes	Strength, corrosion resistance, low density	Pipes, panels, process plant
Composites	Fibre reinforced plastics, metals or ceramics	High toughness; high strength/weight	Aircraft and other transport components
Construction Materials	Building stone, cement	Durable, plentiful supply	Building habitations, roads, bridges
Timber	Wood, wood composites	Ease of fabrication, strength	Furniture, buildings
Fibre	Cotton, nylon, glass	Diverse; manufacturing and handling ease	Textiles, fibre/plastic composites
Paper	Paper, paperboard	Diverse	Printing, decorating

Table 2: Techno-economic areas of impact to Society and materials research and engineering priorities /2/ (Part 1)

(A) HOUSING AND OTHER CONSTRUCTIONS

● Subareas

Construction Machinery  
Highways, Bridges, Airports, etc.  
Individual and Multiple Unit Dwellings  
Industrial and Commercial structures  
Mobile Homes  
Plumbing, Heating, Electrical, etc.

● Materials

- Plastics: develop plastics and easy fabrication methods for use in housing; plastic structures
- Composites: multilayer panels; composites for structural uses; blended ceramics in liquid form; low cost; corrosion-resistant concrete; reinforcement composites to replace steel and concrete
- Adhesives, Coatings, Finishes, Seals: sealants, new joining methods; improved enamel for plumbing

(B) CONSUMER GOODS

● Subareas

Apparel and Textiles  
Furniture  
Household Appliances - Electronic (TV, Radio, Hi-Fi, etc.)  
Household Appliances - Nonelectronic (refrigerators, ranges, air conditioners, vacuum cleaners, etc.)  
Leisure and Sports Equipment  
Packaging and Containers  
Printing and Photography

● Materials

- Plastics: stronger plastics; wear resistance; less brittleness; non-flammable plastics; impact-resistant plastics; biodegradable plastics; high-impact foams; conducting plastics; semiconducting plastics
- Adhesives, Coatings, Finishes, Seals: Resistant polymers and rubbers; corrosion protection; enamels; hot-water tank coatings; self-cleaning coatings for ranges; reduce permeability of packaging films; bonding; fastening; adhesive joining of fabrics
- Wood and Paper: Wet strength of corrugated paper; fireproof paper

Table 2: Techno-economic areas of impact to Society and materials research and engineering priorities /2/ (Part 2)

(C) PRODUCTION EQUIPMENT

● Subareas

Farm and Construction Machinery  
Industrial Drives, Motors, and Controls  
Industrial Instrumentation  
Machine Tools  
Process Equipment

● Materials

- Ferrous Metals and Alloys: harder dies; better cutting tools; better saws; rust resistance
- Non-ferrous Structural Metals and Alloys: cold-forming metals; improved wear and fatigue properties
- Lubricants, Oils, Solvents, Cleansers: tribology-lubricants; wear and abrasion resistance

(D) TRANSPORTATION EQUIPMENT

● Subareas

Aircraft  
Automotive  
Guided Ground Transportation (rail, nonrail)  
Water

● Materials

- Adhesives, Coatings, Finishes, Seals: Adhesives and sealants for aircraft; adhesives for automobile bodies, frames, and repairs; coatings for automobile mufflers; coatings for turbine blades; seals for gas turbines; refractory coatings
- Lubricants, Oils, Solvents, Cleansers: wear, abrasion resistance
- Ferrous Metals and Alloys: improved strength/weight; improved high-temperature properties; corrosion resistance
- Non-ferrous Structural Metals and Alloys; development of titanium and beryllium alloys; superalloys; high-temperature materials for turbine engines
- Plastics: for automobile bodies; composites; higher strength/weight
- Rubbers: wear and reliability of tires; fabrication processes for tires; castable tires; nondestructive testing for tires

Table 2: Techno-economic areas of impact to Society and materials research and engineering priorities /2/ (Part 3)

- Composites: develop composites for use in engine and bodies of automobiles and aircraft; joining metals

(E) COMMUNICATIONS, COMPUTERS, CONTROL

- Subareas

- Commercial Radio and TV Equipment
- Computers
- Electronic Components
- Equipment for Guidance and Control of Transportation
- Teaching Equipment
- Telephone and Data Networks and Equipment

- Materials

- Elemental and Compound Semiconductors: for electronic circuits; large-scale integration; for displays; for solid-state lasers; for semiconductor memory; variable bandgap; high-temperature semiconductors
- Thin Films: for large-scale integration; for light-emitting diodes; of II-VI compounds; control of metalization; thin-film memories; thin-film integrated optical devices; epitaxy; perfection of thin films; bubble memories
- Ceramics: substrates, oxide layers, dielectrics; integrated optics; encapsulation; laser windows
- Glasses and Amorphous Materials: optical transmission; integrated optics; laser windows; amorphous semiconductors; radiation-hard switches; radiation damage; glass for passivation; glass/metal seals
- Inorganic, Nonmetallic Elements and Compounds: electro-optic microelectronics; sensors; displays; modulators; detectors; bubble memories

(F) ENERGY

- Subareas

- Batteries and Fuel Cells
- Direct Conversion
- Electronic Transmission and Distribution
- Fuel Transmission and Distribution
- Nuclear Reactors Thermonuclear Fusion
- Turbines and Generators

- Materials

- Ceramics: high-temperature materials for burners; for plasma containment; high-voltage insulators; ceramics for turbine blades



Table 2: Techno-economic areas of impact to Society and materials research and engineering priorities /2/ (Part 4)

(G) ENVIRONMENTAL QUALITY

● Subareas

Mining and Raw Material Extraction  
Pollution  
Recycling and Solid Waste Disposal  
Reliability, Safety, Maintainability  
Substitution Opportunities  
Working Conditions

● Materials

- Plastics: flammability; toxicity; reproducibility of properties; flame retardant; wear; recyclable polymers; scrap polymers used as fuels

(H) HEALTH SERVICES

● Subareas

Artificial Organs  
Medical Electronics  
Medical Equipment (including dental)  
Prosthetic Devices (including dental)

● Materials

- Plastics: membranes; artificial teeth; dental adhesives; artificial heart valves; encapsulants for implants; containers for blood
- Prosthetic and Medical Materials: implants; artificial organs, bones, teeth, tissue and membranes; compatibility and biological response
- Fibres and Textiles: membranes, fine wires, organ replacements
- Rubbers: artificial organs, tissue, membranes
- Composites: for implants; bone and tooth replacements; joints; pins; matching strength and stiffness
- Organo- and Organometallic compounds: prothesis-tissue interface; adhesion between bone and tissue; for implants

Table 3: Raw materials export as percentage of the total export in selected developing countries (Part 1)

Country	Product	Percentage of 1 3 product products	
Algeria	Crude Petroleum 89, Gas 5 Petrol.Products 2	89	96
Angola	Crude Petroleum 40, Coffee 30, Prec.Stones 9	40	79
Benin	Cotton 36, Cocoa 30, Veg.Oil 19	36	85
Bolivia	Non-Ferr.Metal Ore 37, Tin 28, Gas 11	37	76
Brunei	Crude Petroleum 64, Gas 32, Petr. Products 4	64	100
Burma	Wood 33, Rice 31, Jute 4	33	68
Burundi	Coffee 85, Cotton 7, Tea 3	85	95
Centr.Afr.Rep.	Prec.Stones 37, Coffee 29, Wood 16	37	82
Chad	Cotton 43, Animals 39, Meat 2	43	84
Chile	Copper 48, Pulp 5, Animal Feeding 5	48	58
Colombia	Coffee 66, Petrol.Products 4, Fruit 3	66	73
Congo	Crude Petroleum 63, Wood 17, Prec. Stones 6	63	86
Costa Rica	Coffee 34, Fruit 19, Meat 7	34	60
Cuba	Sugar 86, Non-Ferr.Metal Ore 7, Fish 2	86	95
Dominican Rep.	Sugar 30, Coffee 16, Cocoa 14	30	60
Ecuador	Crude Petroleum 40, Coffee 17, Cocoa 17	40	74
El Salvador	Coffee 35, Cotton 16, Clothing 4	35	55
Ethiopia	Coffee 78, Skins 8, Petr.Products 4	78	90
Fiji	Sugar 69, Veg.Oil 13, Fish 9	69	91
Gabon	Crude Petroleum 73, NF Metal Ore 10, U-Ore 8	73	91

Table 3: Raw materials export as percentage of the total export in selected developing countries (Part 2)

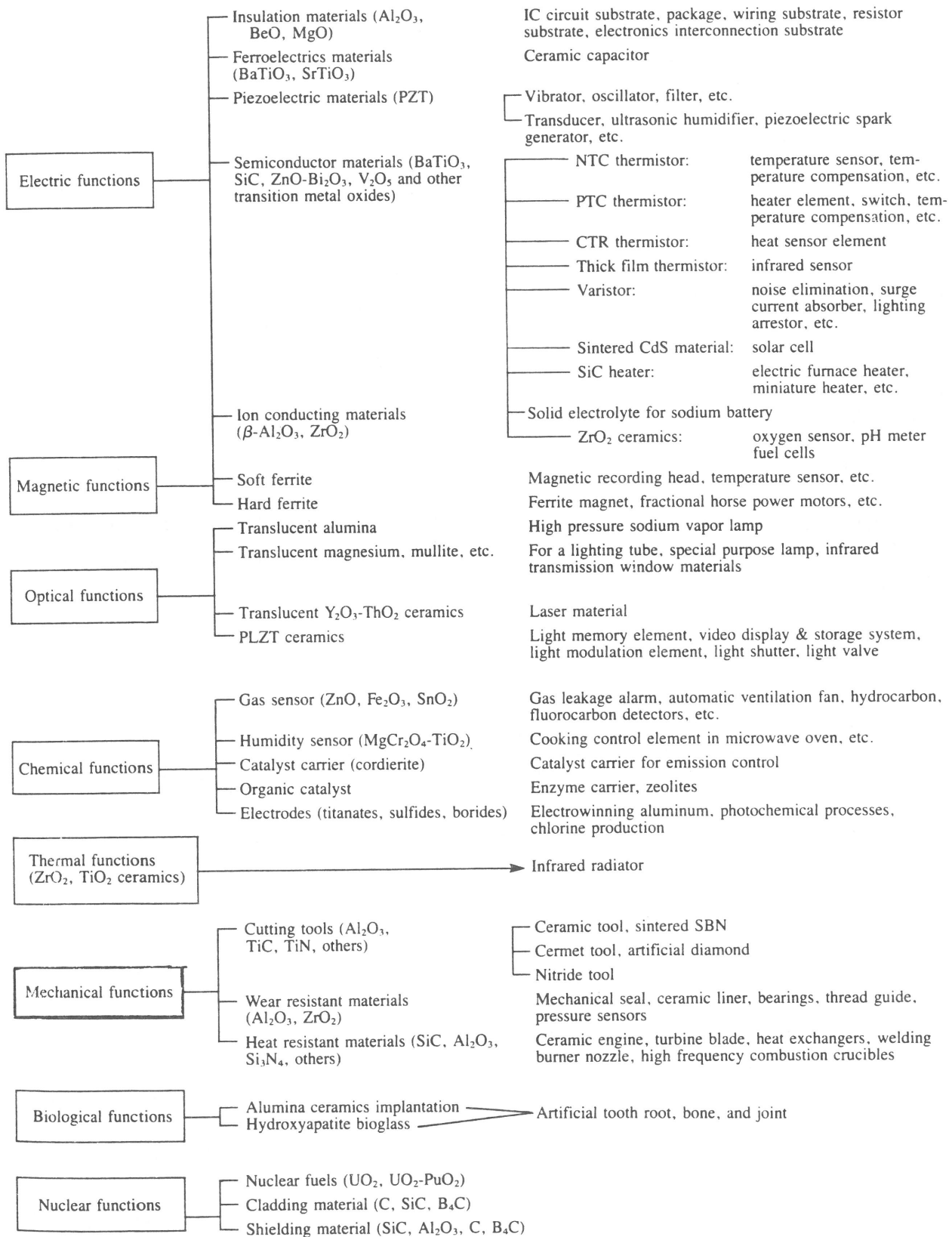
Country	Product	Percentage of	
		1 product	3 products
Ghana	Cocoa 76, Aluminium 11, Wood 6	76	93
Guinea-Bissau	Oil Seeds/Nuts 67, Fish 17, Fruit 3	67	87
Honduras	Coffee 35, Fruit 25, Wood 7	35	67
Indonesia	Crude Petroleum 60, Wood 8, Rubber 6	60	74
Iran	Crude Petroleum 94, Petrol. Products 4, Gas 1	94	99
Iraq	Crude Petroleum 98, Petrol. Products 1, Fruit 1	98	99
Ivory Coast	Cocoa 39, Coffee 26, Wood 10	39	75
Kenya	Coffee 34, Petrol.Products 19, Tea 17	34	70
Liberia	Iron Ore 56, Rubber 14, Wood 10	56	80
Libyan ASPJ	Crude Petroleum 93, Petrol. Products 5, Gas 2	93	100
Madagascar	Coffee 41, Spices 30, NF Metal Ore 4	41	75
Malawi	Tobacco 58, Tea 20, Sugar 9	58	87
Mali	Cotton 37, Animals 26, Oil Seeds/Nuts 7	37	70
Mauritania	Iron Ore 70, Fish 16, NF Metal Ore 4	70	90
Mauritius	Sugar 68, Tea 3, Fish 2	68	73
Nicaragua	Coffee 31, Cotton 23, Meat 11	31	65
Niger	Uranium Ore 78, Animals 10, Veg. Oils 2	78	90
Nigeria	Crude Petroleum 90, Cocoa 7, Oil Seeds/Nuts 1	90	98
Panama	Fruit 29, Petrol. Products 25, Fish 13	29	67
Rwanda	Coffee 61, Tea 15, NF Metal Ore 6	61	82

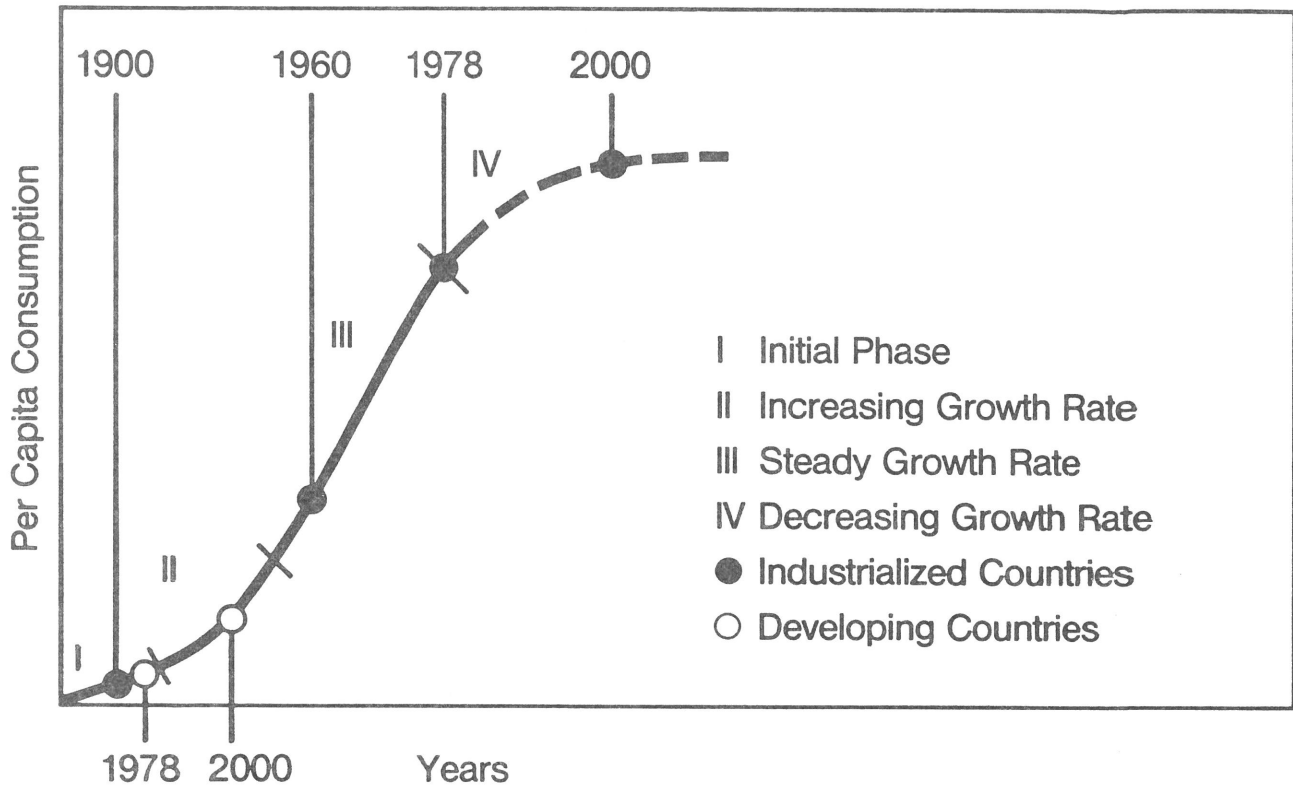
Table 3: Raw materials export as percentage of the total export in selected developing countries (Part 3)

Country	Product	Percentage of 1 3 product products	
Sierra Leone	Prec. Stones 63, Cocoa 15, Coffee 12	63	90
Somalia	Animals 88, Fruit 8, Skins 2	88	98
Sri Lanka	Tea 49, Rubber 15, Petrol. Products 6	49	70
Sudan	Cotton 52, Oil Seeds/Nuts 22, Animals 7	52	81
Syrn.Arab.Rep.	Crude Petroleum 61, Cotton 16, Vegetables 3	61	80
Uganda	Coffee 87, Cotton 5, Tea 2	87	94
Upper Volta	Animals 37, Cotton 32, Oil Seeds/Nuts 10	37	79
Zaire	Copper 35, Coffee 21, NF Metal Ore 14	35	70
Zambia	Copper 86, NF Metals 5, Zinc 3	86	94

Source: UNCTAD, Handbook of International Trade and Development Statistics, Supplement 1981, United Nations, New York 1982

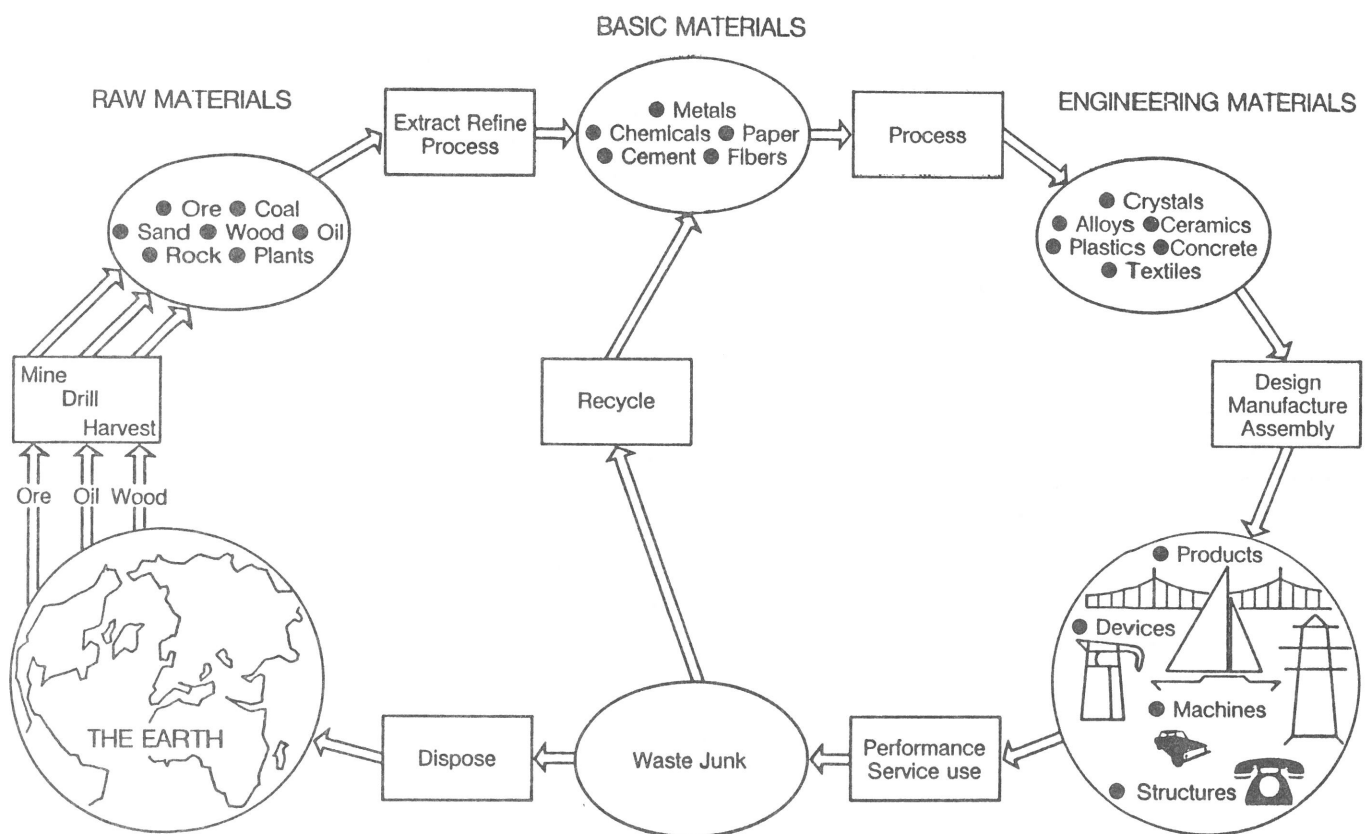
**Table 4:** Classification of high-technology ceramics by function /13/





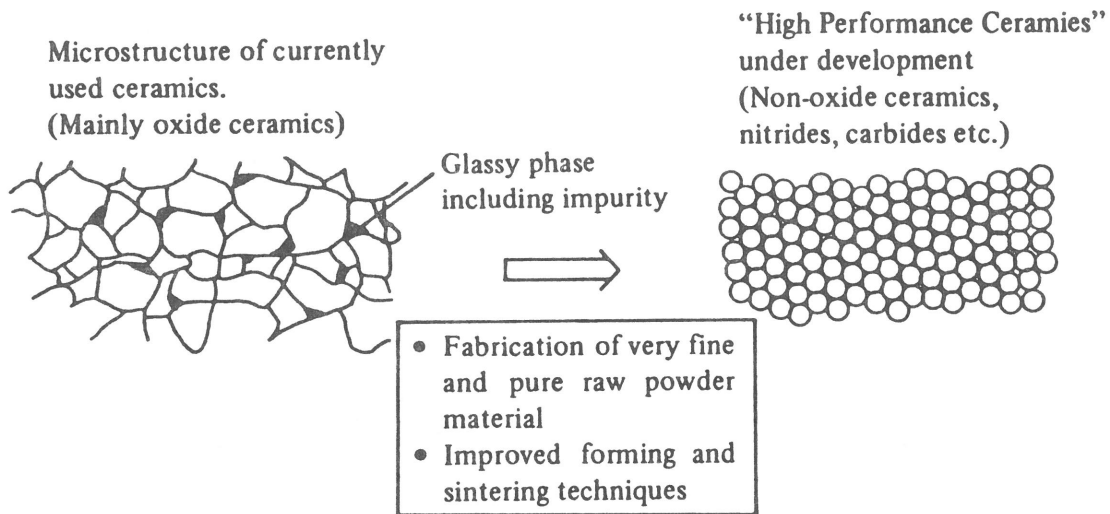
**Figure 1: Development of Per Capita Raw Material Consumption (Schematic)**

Source: D. Altenpohl, Materials in world perspective, Springer-Verlag, Berlin, Heidelberg, New York 1980



**Figure 2: The Total Materials Cycle**

Source: Materials & Man's Needs, Materials Science and Engineering, National Academy of Sciences Washington, D.C., 1974



- Characterized by fairly large size (some  $10\mu\text{m}$ ) and a substantial amount of impurities and porosity.

- Characterized by a homogeneous distribution of fine grain sizes (not larger than  $1\mu\text{m}$ ) and little porosity.

Figure 3: Example of Materials Research Activities:  
High Performance Ceramics (Schematic)

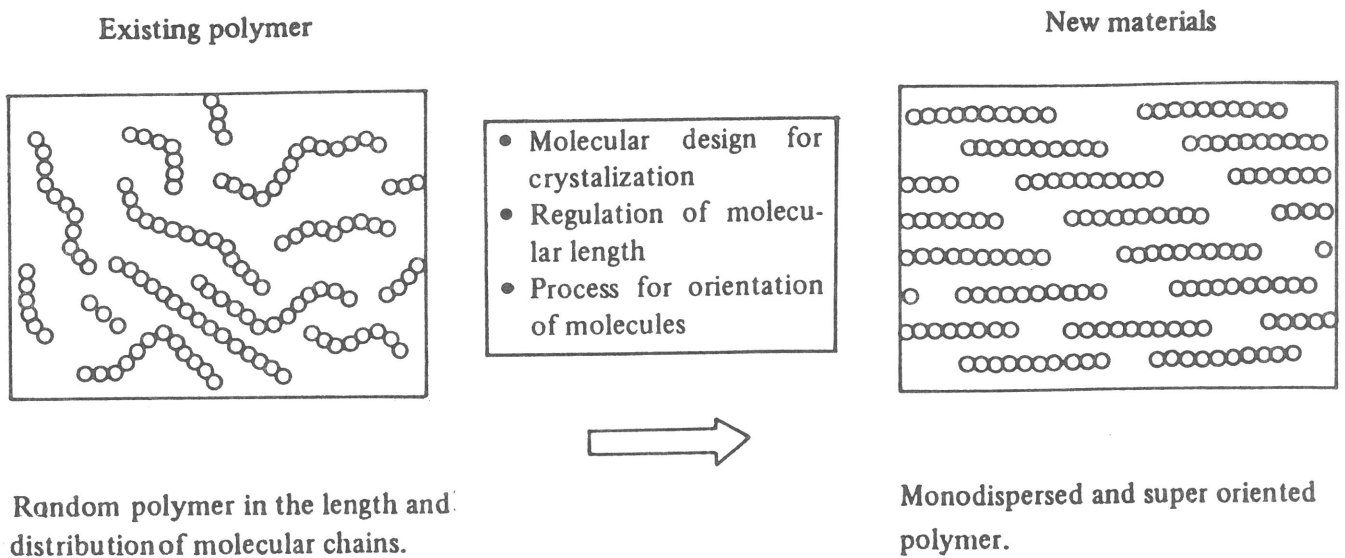


Figure 4: Example of Materials Research Activities:  
High Performance Plastics (Schematic)

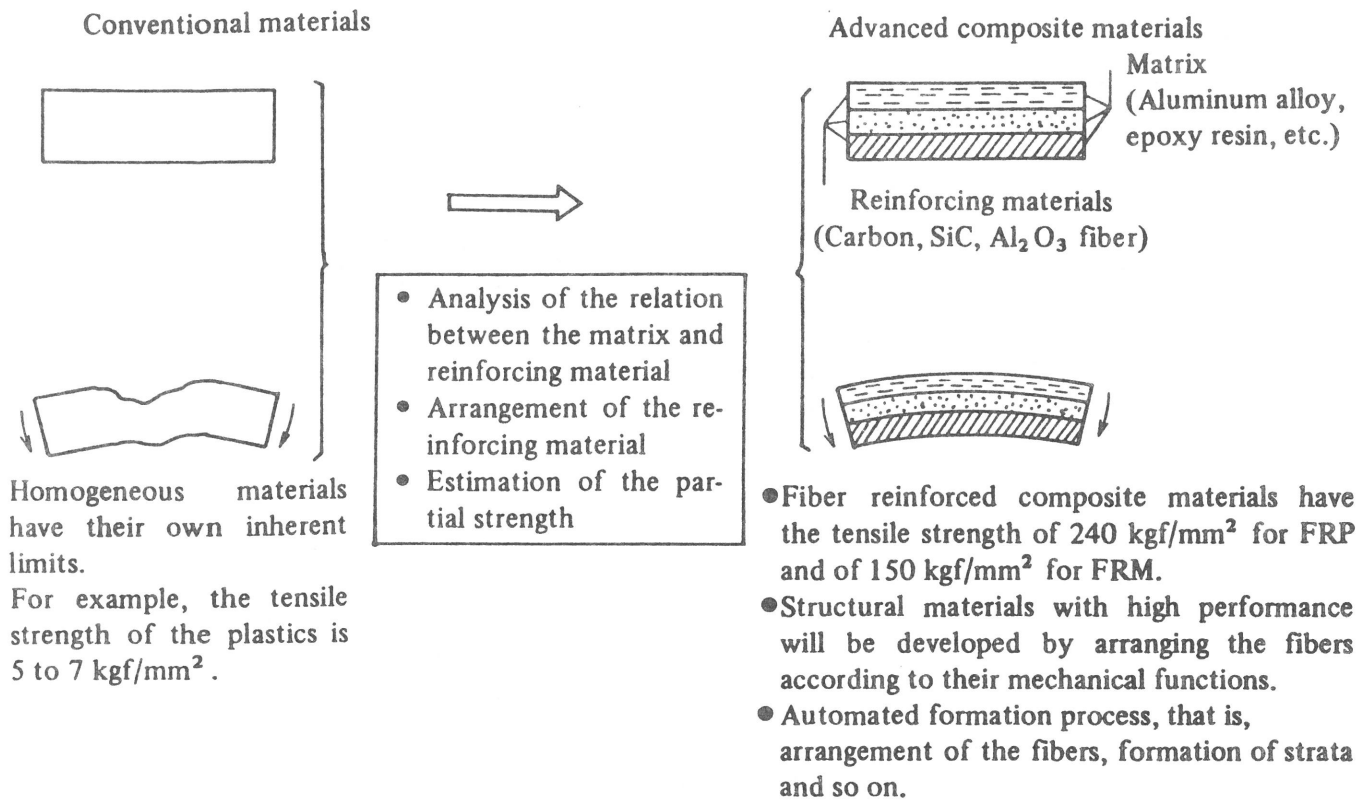


Figure 5: Example of Materials Research Activities:  
Advanced Composite Materials (Schematic)



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