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PROCEEDINGS OF THE HIGH-LEVEL WORKSHOP ON THE IMPLICATIONS OF NEW AND ADVANCED MATERIALS TECHNOLOGIES FOR THE ECONOMIES OF THE ESCWA COUNTRIES

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Preface

These proceedings are part of the ESCWA work programme in the field of Science and Technology for the biennium 1994-1995. The programme emphasizes endogenous technological capacity-building, which is of crucial importance to the region in the years ahead. We would like to thank Professor Antoine Zahlan and Mr. Lakis Kaounides, who acted as consultants in the preparation of the main technical studies presented here. A host of other experts, mentioned in the acknowledgements, also made important contributions to these proceedings.

Acknowledgements

The present proceedings are of the workshop on the "Implications of New and Advanced Materials Technologies for the Development of the ESCWA Countries", which was organized by the Science and Technology Programme of ESCWA in Damascus in September 1992. The workshop would not have been possible without the extensive support of the following five institutions: the United Nations Industrial Development Organization (UNIDO), which provided consultants, contributed to the substantive materials developed for the workshop and actively participated in the workshop; the Islamic Development Bank (IDB) and the Canadian International Research and Development Centre (IDRC) which made generous contributions which enabled to extend the coverage and country participation in the workshop; The Syrian Scientific Studies and Research Centre and the Arab School for Science and Technology in Damascus which provided the meeting venue, printing facilities and generous hospitality. The workshop was held on the premises of the Higher Institute for Applied Science and Technology in Damascus which also organized sightseeing tours for the participants. They all deserve our thanks and appreciation.

We would also like to thank the following authors and institutions whose contributions appear in these proceedings: Mr. Jürgen Lexow, of *Bundesanstalt für Materialforschung und Prüfung* in Berlin, Germany, Mr. Lakis Kaounides of the City University, London, United Kingdom of Great Britain and Northern Ireland; Mr. M. Kamal Hossain of the National Physical Laboratory, United Kingdom; Professor John Wood of the University of Nottingham, United Kingdom; Mrs. A.O. Aribisala of the Raw Materials Research and Development Council, Federal Ministry of Science and Technology, Lagos, Nigeria; Professor R.S. Ganapathy of the National Materials Project in India; Mr. Mohammed Kamel Mahmoud, former President of the Academy for Scientific Research and Technology in Egypt; Mr. Yousif Mazhar, First Deputy Minister, Ministry of Industry and Minerals, Egypt; the National Research Centre (NRC) and Professor N.M. Ghoneim, Mr. A.M. Attia and Mr. N.A. Saleh, and Professor W.I.A. Fattah of NRC; the Royal Scientific Society (RSS) and Ms. Falak Al-Sarraf of RSS; the Syrian Scientific Studies and Research Centre (SSRC), and Mr. Omar F. Bizri of SSRC, and Professor Antoine Zahlan for his valuable contribution in the preparation for and during the workshop. We would also like to thank the workshop participants for their contributions in the discussions and in the formulation of the conclusions and recommendations.

Special thanks, however, are due to Professor Wathiq Chahid, Director of SSRC in the Syrian Arab Republic for providing the support of SSRC for the workshop, and to Mr. Ahmed Haj Said, Director of the Arab School for Science and Technology, for his tireless support and generous hospitality throughout the duration of the workshop.

A number of other experts, as well as representatives from national and international institutions, also contributed to the substantive material and the discussions of the workshop. The titles of the papers presented in the workshop are mentioned in the list of papers presented to the workshop. Altogether 23 papers were presented. The significance of these contributions was evident in the workshop. It was not possible, however, to reproduce all the papers in these proceedings. Only those papers which addressed the issues within national, regional, and international frameworks could be included. Those which addressed specific material issues have been reproduced for distribution upon request.

We would like to thank the following authors of papers which were read at the workshop: Professor Ian Marshal, Department of Mechanical and Manufacturing Engineering, Paisley University; United Kingdom; Mr. Mukkaalli Rama Murthy, Consultant, Bombay, India; Mr. William Weppner, Chairman, Education in Materials Technology Foundation, Netherlands; Mr. Ragaey Bassyouni, Chairman, Arab British Helicopters Company, Egypt; Mr. Ibrahim El-Mihy, Consultant, El-Nasr Glass Company, Egypt; Mr. Ahmed El-Sayed Atty, Arab Company for Industrialization, Egypt; Professor Wafa Abdel-Fattah and W.G. Osiris, National Research Centre, and Cairo University respectively, Egypt; Professor Ghazi Derwish, Baghdad University, Iraq; Professor Jabir Shanshoul, University of Technology, Baghdad, Iraq; Mr. Zuheir Al-Karmi, retired Vice-President, College of Science and Technology, Amman, Jordan. We would also like to mention with special thanks Mr. Ali Dajani, Advisor, Amman Chamber of Commerce and Industry, for his valuable comments and contributions to the discussion of the workshop. Thanks are also due to Professor Malcolm McLaren, Director, Centre for Ceramic Research, Rutgers University, New Jersey, USA; Mr. Mammo Muchie, Middlesex University, London, United Kingdom, who sent their papers but were unable to attend the workshop.

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EXPLANATORY NOTES

Symbols of United Nations documents are composed of capital letters combined with numbers. Mention of such a symbol indicates a reference to a United Nations document.

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All references to dollars ($) are to United States dollars unless otherwise specified.

Bibliographical and other references have, wherever possible, been verified.

The views expressed in individual papers are those of the authors and do not necessarily reflect the views of the Economic and Social Commission for Western Asia.

ABBREVIATIONS

C-MET	Centre for Materials for Electronics Technology.
CECRI	Central Electrochemical Research Institute.
CGCRI	Central Glass and Ceramic Research Institute, Calcutta.
CII	Confederation of Indian Industry.
CLRI	Central Leather Research Institute, Madras.
CSIR	Council for Scientific and Industrial Research.
DMRL	Defence Metallurgical Research Laboratory.
DOE	Department of Electronics.
DRDL	Defence Research and Development Laboratory.
EIL	Engineers India Ltd.
HAL	Hindustan Aeronautics Ltd.
HCL	Hindustan Copper Ltd.
HINDALCO	Hindustan Aluminium Company Ltd.
ICICI	Industrial Credit and Investment Corporation of India Ltd.
ISRO	Indian Space Research Organization.
IWST	Institute of Wood Science and Technology, Bangalore.
MECON	Metallurgical and Engineering Consultants of India Ltd.
NAL	National Aeronautical Laboratory, Bangalore.
NALCO	National Aluminium Company Ltd.
NCL	National Chemical Laboratory, Pune.
NML	National Metallurgical Laboratory.
RRL	Regional Research Laboratory.
SAIL	Steel Authority of India Ltd.
SMCL	Southern Magnesium and Chemicals Ltd.
TIFAC	Technology Information, Forecasting and Assessment Council.
TISCO	Tata Iron and Steel Company Ltd.
TNML	Tamil Nadu Magnesium Ltd.
VSSC	Vikram Sarabhai Space Centre.

INTRODUCTION

This study examines the impact of the advances in materials technology on the world economy and its implications for the development of the ESCWA member countries. The information in these proceedings shows that the developments in the field of materials are far-reaching and constitute a fundamental break with past practices in the mode of design, fabrication and utilization of materials in the manufacturing industry. One of the main characteristics of this new development is that materials scientists can intervene in the atomic and molecular structure of matter and can design and process materials and tailor them for specific applications.

The research director of a major chemical group summarized the development as follows:

> "Since the start of the eighties the new results and findings of basic scientific research have increased our knowledge further and even more rapidly than previously. Molecular biology is enabling us to constantly increase our understanding of the connections between molecular structures, interactions and biological processes—including even the fundamental questions of life. Extremely refined physical methods such as tunnel scanning electron microscopy are affording us deep insights into molecular and atomic structures and processes. The combination of quantum theory and the use of ever more powerful computers is allowing us to predict important properties and the resultant behaviour of substances under specified conditions.
>
> "New methods of synthesis are opening up previously unknown classes of chemical compounds, and exciting new properties of a wide variety of material systems such as those of ceramic high-temperature superconductors or liquid crystalline polymers are constantly being discovered".[1]

The synthesis of entirely new materials and greatly improved traditional materials, such as plastics, synthetic resins, fibres, films, pure glasses, electronic and structural ceramics, polymer and metal matrix composites, advanced aluminium and steel alloys are making possible products of ever greater technological sophistication, for example the new generation of jet engines and aircraft structures, cars, robots, colour televisions, videotape recorders. The shift of user industries towards high technology and increasing sophistication is placing ever higher technical and performance requirements from the side of materials. This has led to the development of new, advanced materials possessing entirely new performance characteristics and combinations of properties unheard of even a decade ago. It has also led to the improvement of conventional materials. In polymer materials, it is now possible to tailor the chemical structure of a molecular polymer to form either random coils in the melt or liquid

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[1] Prof. Heinz Harnisch, Research Director, Hoechst. See "Advanced Materials in High Technology and World Class Manufacturing: The materials revolution and the competitive challenge from Japan and S.E. Asia in the 90's", Lakis C. Kaounides (ed), UNIDO Technology Trends Series, Vienna, Austria, December 1992; *Advanced Materials Technologies—Strategies for Industrial Competitiveness and Growth into the 21st Century*, United Nations Industrial Development Organization/Institute of Materials Books, London, Spring 1993. Lakis C. Kaounides and Mammo Muchie (eds), *The Materials Revolution and Developing Economies*, Frank Cass: London, Spring 1993.

crystal so that, like uncooked spaghetti, it forms a strictly parallel packing as stiff bars prior to solidification.

The tailoring of the molecular structure naturally requires the development of new processing technologies in order to achieve the carefully controlled microstructure and desired properties. The chemical producers are not only developing further synthetic polymers, technical plastics, synthetic resins, fibres and films but are also engaged today in the development of polymer alloys yielding materials with entirely new properties. Combining different polymers creates entirely new possibilities by adding properties together, and this has led to the application of the alloying principle, originally associated with metallurgy, to fibres, films and paints in many industrial laboratories around the world. Another major research area is in high-performance polymers to satisfy the demands of automotive, aerospace, electrical and electronics industries.

The advancement in materials technology has meant the application of the materials science and engineering structure (synthesis/processing/properties/performance) continuously across all classes of materials. The new science and engineering knowledge base has consequently opened up the potential for large improvements in the properties and processing technologies of conventional materials as well as the spawning of a large array of knowledge in intensive advanced materials tailored for specific applications.

In a sense, all materials are "new" today. This is a central aspect of the materials advances. These developments are of critical importance to developing economies, the vast majority of which are still dependent on the primary commodity export. The latter is now completely enmeshed in the scientific, engineering and technological developments affecting conventional materials, new advanced materials and the materials requirements of new industries. Many such economies need to re-evaluate the desirability of remaining at the early stages of commodity production. They need to consider the technological and organizational responses required to successfully protect their commodity exports (e.g. petrochemicals, primary aluminium, and natural rubber). They must carefully study the points of entry into their industry at subsequent stages of the materials production cycle. As this study will show, however, developments in the materials field are inseparable from developments in industry. Thus, strategies aimed at identifying existing sources and new sources of acquired comparative advantage need to be thoroughly studied.

In the following pages, the implications of new and advanced materials technologies for the development of the ESCWA member countries are discussed in five parts.

Part one includes four papers: the first is by Jürgen Lexow from *Bundesanstalt für Materialforschung und Prüfung* in Berlin, Germany. It presents a comprehensive coverage of the new and advanced materials covered in this volume. It discusses the status and trends in materials technologies, mainly in the European context. It refers to the applications of advanced materials in various areas and shows how these applications contributed to improving the functions, quality and performance of engineering components and of industrial products. The paper also shows why, in dealing with industrial and materials technologies, a system approach must be applied.

The second paper is by Lakis Kaounides of the City University of London. This is the most extensive technical study in the proceedings. It begins by defining new materials and discusses the characteristics and consequences of the materials revolution, the current transition from metal-based to new-materials-based economies, the global restructuring that is taking place in basic industries (ferrous and non-ferrous metals, chemicals, petrochemicals, steel, aluminium, alloys and cement), the implications of advances in materials technologies for national comparative advantage, including changes in industrial organization and production of advanced products, the future materials science and technology strategy in advanced countries, and the implication of the changes brought about by the revolution in materials technologies for developing countries especially regarding the development of infrastructure, materials science and engineering, traditional row materials and environment. This paper also includes three annexes relating to chemicals in Japan, chemicals and petrochemicals in the Republic of Korea, and petrochemicals in Taiwan Province of China.

The third paper is by Kamal Hossain of the National Physical Laboratory in the United Kingdom. It addresses the importance of testing and evaluation as applied to a number of classes of new materials, notably high-temperature ceramics and metal- and polymer-matrix composites. It also describes testing and evaluation activities in a number of industrialized countries and elaborates issues relating to the development of international standards. The paper concludes by considering international cooperation in pre-standard research.

The fourth paper is by John Wood of the University of Nottingham, United Kingdom of Great Britain and Northern Ireland. Based on European examples of collaborative industry-government-university arrangements, this paper discusses the analogies required to develop a strategy for materials education and research, and it describes programmes which could be applied in the ESCWA region.

Part two introduces the experiences of two developing countries, namely Nigeria and India, and the experience of UNIDO in the field of new and advanced materials technologies. The paper on Nigeria was prepared by A.O. Aribisala of the Raw Materials Research and Development Council, Federal Ministry of Science and Technology, Lagos. The Indian experience is a shorter version of the original, comprehensive paper prepared by R.S. Ganapathy of the National Materials Policy Project in India. Mrs. Aribisala's paper summarizes the experience of Nigeria and points out that, in addition to their concern about basic needs, developing countries, particularly those which are heavily dependent on export of raw materials, "cannot ignore the threat posed by the replacement of traditional materials with new materials". She shows why it is essential to learn about this challenge and how to make use of the potential within the resources available. She concludes by suggesting a number of policy measures in this respect and for promoting cooperation among developing countries. The Indian paper brings out, by discussing the Indian case, the proper components of materials strategy and the objectives that a materials council in the region should serve. The UNIDO paper was presented by Messrs K. Venkataraman and V. Kojarnovitch. They discussed the current and future activities of UNIDO in the field of new and advanced materials and its cooperation policy in this field.

Part three includes three case-studies (one each on Egypt, Jordan, and the Syrian Arab Republic) from the region's own experience. Three papers were presented on Egypt's experience: one by Mohammed Kamel Mahmoud, another by Yousif Mazhar, and the third by the National Research Centre (NRC). These three contributions have been condensed into one paper in the present proceedings. The main issues in each have been selected in such a way as to provide a full picture of Egypt's experience. Thus, the paper by Kamel Mahmoud sets the scene in the introduction and suggests a strategy for Egypt in the field of new materials at the end. Yousif Mazhar's paper reviews the whole range of applications and possible uses of new materials in Egypt. The NRC paper refers to most of the research activities in new materials that are either being carried out or considered. The Jordanian paper and the Syrian paper were prepared respectively by the Royal Scientific Society and the Syrian Scientific Studies and Research Centre/Arab School. They provide a comprehensive picture of the uses of and prospects for the applications of new and advanced materials in those two countries. They also refer to the problems and impediments each country is facing in the utilization of the opportunities created by the advances in materials technologies. The paper for the Syrian Arab Republic has an annex with the main functions of a proposed centre for new materials for the ESCWA region.

Part four deals with the implications of the advances in materials technologies for the socio-economic development of the ESCWA member countries. It studies these implications from the supply and demand sides. It analyses the present state of affairs in the region regarding science and technology and points out some of the main obstacles in utilizing technological advances in the region. It also identifies the main prerequisites for efficient utilization of the region's scientific and technological endowments and the modalities for dealing with the prevailing inadequacies. It concludes by making a number of policy recommendations for action at the level of the government, public and private sectors.

Part five consists of the recommendations formulated by the participants of the workshop which was organized under the title of this study in the Arab School for Science and Technology in Damascus in September 1992.

Finally, at the end of each paper there is a transcription of the discussion during the workshop regarding the papers included in that part.

PART ONE

Paper One

ADVANCED MATERIALS TECHNOLOGIES: STATUS AND DEVELOPMENT TRENDS

Jürgen Lexow

Synopsis

Materials constitute the physical matter of all things produced by humans; they are thus a key factor in technological and economic development. The application of advanced materials in various areas of contemporary technology can lead to improvements in the function, quality and performance of engineering components and industrial products. Industrial and materials technologies must be seen today in a systems approach as part of the "total product cycle": from raw-materials processing to the engineering of materials, the design and fabrication of products, their performance, testing and assessment and, finally, the disposal or preferably the recycling of waste. In this overview paper, the status and trends in materials technology—related mainly to developments in Europe—are outlined. The paper is based on a recent comprehensive study made on behalf of the Commission of the European Communities and entitled "Industrial and Materials Technologies: Research and Development Trends and Needs".

1. *Review of materials science and engineering*

Materials play an enabling role in all industrial technologies. Therefore, the various areas of materials science and engineering will be reviewed in brief.

1.1 *Materials research*

The trends and opportunities in materials research have been recently studied in depth by the Materials Research Advisory Committee of the United States National Science Foundation (Ref. 1.1).[1] Several overall trends in the field are noted, including:

(a) Expansion of the frontiers of extreme physical condition (temperature, pressure, materials purity, etc.) leading to the discovery of new phenomena;

(b) The increasing sophistication and power of theory to confront the complexity of real materials. This is aided by computers and versatile numerical techniques on one hand, and effective abstract concepts from statistical mechanics on the other;

(c) The careful study of model systems which isolate for study certain fundamental or technologically important systems. Examples range from clean surfaces of semiconducting and metallic single crystals to simple, disordered, amorphous or glassy solids and to exotic liquid crystals in bulk and in films;

(d) A shift towards the study of complex materials and systems. Surfaces, interfaces, small particles, thin films and submicron structures (e.g. "nano-crystallic metals"), complex composite materials, systems with intricate microstructures, highly anisotropic solids and quasi one- and two-dimensional materials are important examples;

(e) Increased sophistication in the methods of materials preparation. This involves advanced chemical synthesis and metallurgical processing as well as more recently developed

[1] For the list of references, see page 46.

fabrication techniques, such as rapid solidification, ultra high vacuum vapour deposition, molecular beam epitaxy, and plasma induced oxidation.

(f) Fuller characterization of materials on the atomic scale, which ultimately determines the macroscopic properties of primary interest. This is made possible by the development of a vast array of diagnostic tools which probe physical and chemical properties on the molecular/atomic scale.

(g) An increasing focus on understanding and controlling the processes used to make materials. The coupling of characterization methods to the fabrication process increasingly permits proper control of the resultant product and the tailoring of materials properties to specific physical requirements for practical applications or for fundamental studies.

1.2 *Materials processing*

Advances in materials often depend on (or are coupled with) progress in processing techniques. Some of the major newer processing techniques currently emerging are (Ref. 1.2):

(a) *Solidification*

Directional solidification has successfully been developed to produce anisotropic structures with improved properties. The first development was columnar grain structures which gave improved creep resistance because of the absence of transverse grain boundaries, which has led to single crystal turbine blades for use in aircraft jet engines. Rapid solidification processing produces non-crystalline (glassy or amorphous) alloys by cooling them very rapidly (about 106 deg/s) from the liquid or gaseous phase in such a way that the atoms are frozen in their liquid configuration. Ribbons obtained by "melt-spinning" are typically 30 to 40 mm thick and 3 to 5 mm wide and can be 100% glassy with a very even section and smooth surface.

(b) *Mechanical alloying*

This process involves dry-milling suitable mixtures of metal and oxide powders in high-energy attrition mills to produce "composite" superalloy powders, an even dispersion of oxide in an already alloyed metallic matrix. This powder preparation may then be directly hot extruded and rolled to base form, followed by heat treatment, to produce the required structure and properties of the oxide dispersion strengthened superalloy (ODS).

(c) *Casting*

Continuous casting, whereby solidified metal is continuously drawn from an open-ended mould continually fed with liquid metal, is now a commercially viable process for aluminium, copper and steel in slab and bar form. Rheocasting is a technique for shaping metal in the semi-solid state. It involves vigorous agitation of the melt during the early stages of solidification, which breaks up the solidifying dendrite structure to form a viscous slurry that can be "cast" as an ingot.

(d) *Powder metallurgy (PM)*

By this technique, the material is first produced in powder form and then consolidated by pressing and high-temperature sintering. Powder forging involves hot forging in closed dies, the pre-forms made by PM techniques. The powder-forged parts are more homogeneous in structure, have more isotropic mechanical properties, and have better dimensional accuracy and surface finish. Hot Isostatic Pressing (HIP'ing) involves simultaneous isostatic pressing (pressure-tight container in a pressure vessel) and sintering. HIP'ing can achieve more than 99% theoretical density in most metals and ceramics.

(e) *Forming*

Certain metals (e.g. Zn-Al, Cu-alloys, some stainless steels and light alloys based on Al and Ti) show super-plasticity, i.e. uniform elongation under slow rates of strain within a certain temperature range. Thus, they can be moulded in a manner similar to thermoplastics. Explosive forming, on the other hand, involves using high- and low-energy explosives to press metals against blocks or into die cavities. By electroforming it is now possible to use standard electroplating tanks and techniques to form the whole component.

(f) *Surface technologies*

A number of surface technologies have been brought to industrial applications in recent years, including Chemical Vapour Deposition (CVD) and Physical Vapour Deposition (PVD). Ion implantation, which has been successfully used to dope semiconductors, has been introduced to the metals industries to allow ion implantation onto the surface of metal components to produce special alloys with unusual properties. Laser surface treatments are now commercially possible, involving surface melting and surface alloying that provide new opportunities for modifying surface structure (surface homogenization, alloying or cladding) in a controlled manner.

1.3 *Structural materials*

Engineering materials for applications in which the mechanical (or mechanical-thermal) properties are critical for design are called "structural materials". Traditionally they comprise mainly the broad classes of metals and alloys, ceramics, polymers and composites made of them. Some of the physical and mechanical properties that lead a designer to choose one material over another are shown in figure 1.1 (Ref. 1.3). Many other properties are also important to a designer, including corrosion and wear resistance, durability, reliability and, always, cost. From the overview data of figure 1.1, the vast spectrum of structural materials with broadly varying properties is obvious. There is an intense, continuous effort to improve structural materials in various directions; only some main trends (Ref. 2.4) can be discussed within the scope of this study.

1.3.1 *Metals and alloys*

Advances in basic metals (Ref. 1.5) are mainly possible through improvements in (a) purity and chemical control; (b) microstructure specifications; (c) processing and manufacturing techniques.

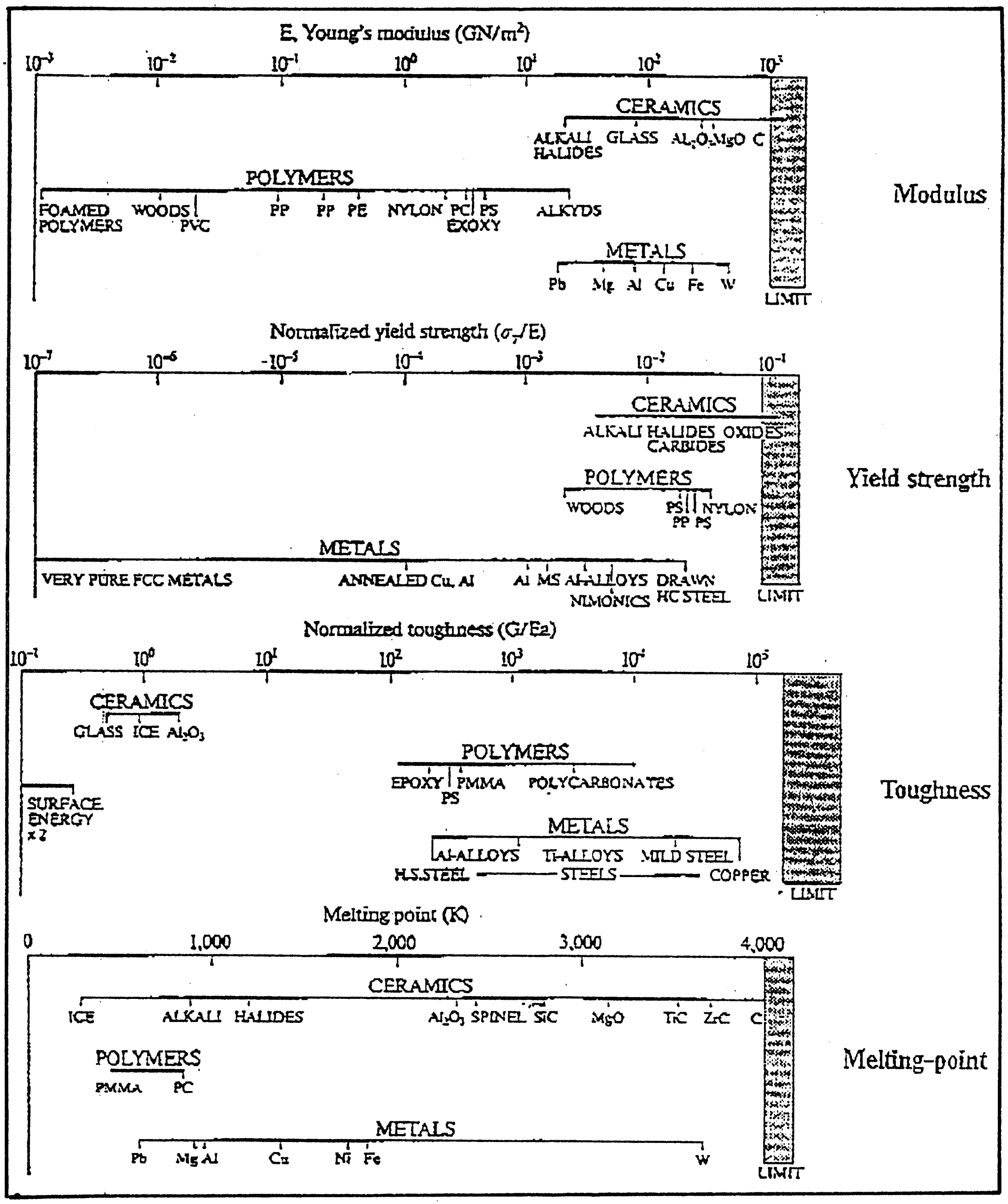


Figure 1.1. PROPERTIES OF ENGINEERING MATERIALS

Advances in steel refining have led to remarkable improvements in composition control and cleanliness. Reduction in oxide and especially sulphide contents have resulted in significant improvements in ductility. A corresponding prospect of comparable importance is the potential removal of phosphorus. Phosphorus increases the sensitivity of high-strength steels to embrittlement phenomena, and its elimination would constitute a major advance in ferrous metallurgy.

An example of solid-state processing that has reached commercial scale in steel making is the controlled rolling of steels that are microalloyed with relatively stable carbide- and nitride-forming elements such as niobium, vanadium and titanium. In this process, particle precipitation is induced by plastic deformation at a controlled temperature during rolling, and a fine grain structure is obtained through a controlled schedule of temperature reduction and rolling. The results are the high-strength low-alloy (ESLA) steels that have been developed over the past few decades. A measure of the techno-economic success of these steels is their increasing utilization in automobiles. According to figure 1.2, the amount of ESLA steel used per vehicle has been increasing even more rapidly in recent years than the lower-density aluminium alloys, plastics and composites.

An important development in the HSLA steels are the "dual phase" steels (Ref. 1.6). By creating a ferritic-martensitic structure with 10 to 20% hard martensite, it is possible to give such a material improved ductility and greater strength than other steels. This structure can be obtained in two ways: (a) by annealing in the austenite-ferrite range followed by rapid quenching (in the case of low alloyed MnV, MnTi or MnNb steels); or (b) by precise rolling and cooling (for the higher alloys of the CrMo or MnSiCo type).

For lightweight, high-strength structures there is considerable interest in research on aluminium-lithium alloys (Ref. 1.6). An aluminium alloy of 2.5% lithium has a weight saving of 9% and a specific stiffness that is 20% higher than that of older aluminium alloys. The strength of this kind of material is obtained by coherent Al_3Li precipitates with dimensions of 10 to 100 nm. One disadvantage of aluminium-lithium alloys is their low elongation at break. This is improved by the addition of 1.3 to 2.1% copper. Grain growth and recrystallization are countered by adding 0.12% zirconium, which also improves stability at high temperatures.

With specific processing techniques, materials with unusual microstructures have been developed in recent years. Two classes of materials which are of great interest for future applications, not only from a structural but also from a "functional" point of view, are glassy metals and nanocrystalline metals:

(a) Some metallic alloys can display a non-crystalline (glassy or amorphous) state if produced by rapid solidification techniques. Examples are metal-metalloid alloys, such as Pd_{80} Si_{20}, Fe_{80} B_{20} and metal-metal alloys, such as Ni_{60} NB_{40}, Cu_{50} Zr_{50}. Metallic glasses are all very strong and stiff; the strongest known, Fe_{80} B_{20}, is stronger than the best carbon fibre and almost as stiff. In addition, the corrosion resistance of metallic glasses is very promising and their electric resistivities are three to four times higher than conventional Fe or Fe-Ni alloys and are almost independent of temperature over wide ranges;

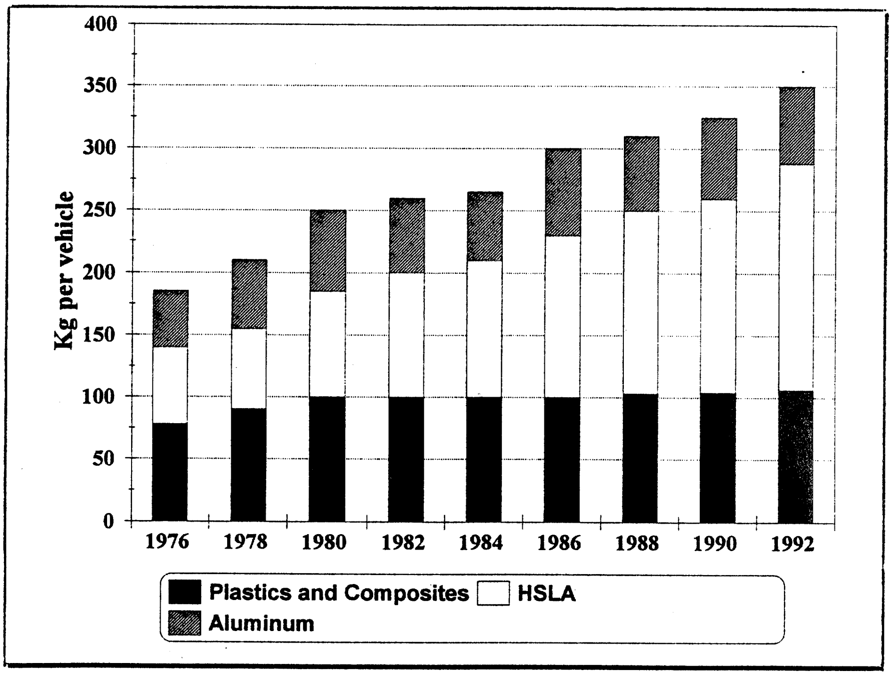


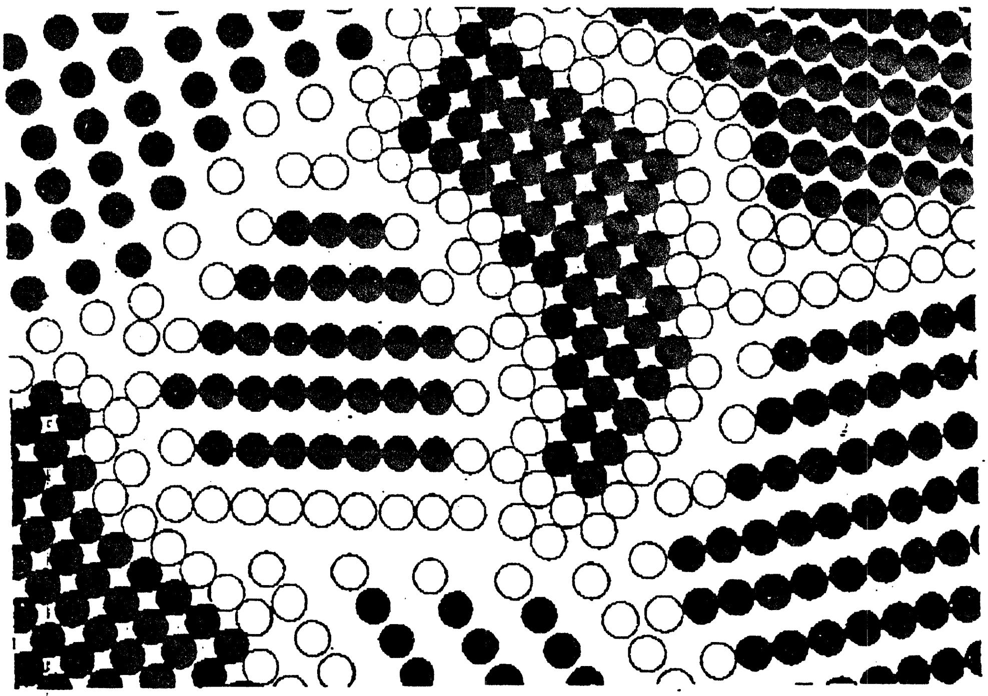
Figure 1.2. MATERIALS USE IN U.S. AUTOMOBILES - STATUS AND TRENDS

(b) Nanocrystalline metals, in which the grain size is of the order of nanometres have been made feasible by evaporation and fine-particle condensation techniques (Ref. 1.7). When the compacted specimen grain size is about 5 nm, the crystalline and interfacial phases have nearly the same volume fraction, assuming a grain boundary thickness of 1 to 2 nm (see figure 1.3). This wholly new type of material can have very different properties from any material previously produced.

1.3.2 *Ceramics*

The newer, special-engineering ceramics of current interest are alumina (Al_2O_3), silicon carbide (SiC), silicon nitride (Si_3N_4), zirconia (ZrO_2) and the Sialons (silicon aluminium oxynitrides). Their main valuable properties include high hardness, high stiffness, relatively low density and high wear- and corrosion resistance. A serious limitation of ceramics for structural applications has been their inherent brittleness and their susceptibility to thermal shock, i.e. they fracture when suddenly cooled or heated. These drawbacks may be improved by reducing the size of "flaws", i.e. the small cracks introduced during raw material handling and manufacturing and by introducing toughening mechanisms through synthetic "crack-retarding entities" which should arrest or close cracks. Thus, the two main routes to improve structural ceramics are (a) refinement of processing and (b) introduction of toughening mechanisms.

Of the multitude of processing techniques, the following three powder synthesis methods are particularly important:



Note: Black circles are atoms allocated to crystalline regions; open circles are atoms allocated to grain boundary regions.

Figure 1.3. STRUCTURE MODEL OF NANOCRYSTALLINE MATERIALS

(a) The preparation of monodisperse oxide powders, starting from alkoxides, using controlled hydrolysis. This method, which is also suitable for the deposition of a layer of oxide materials, is relatively costly because of the investment in equipment. It is widely used for powder preparation on a laboratory scale when extremely high purity is required;

(b) The sol-gel process starts with an aqueous dispersion of ceramic particles. The dispersion is gelled by the extraction of water, after which the powder is obtained by drying the gel. The particles are generally small (5 to 50 nm) and spherical. Despite their relatively high production costs, sol-gel powders are used for a number of important applications;

(c) The preparation of powders is sometimes carried out through a gas phase process using a laser or a plasma. Here, for example, silicon nitride is made from the gases silicon tetrachloride and ammonia or from silicon tetrachloride, nitrogen and hydrogen, the reaction product being formed by laser or plasma excitation. The great advantage of this (complex) technique is that very fine powders can be made with particle sizes down to 10 nm.

The current approaches to increase the toughness of engineering ceramics include reducing the size and concentration of pre-existing crack initiators (such as microcracks and pores) by decreasing grain sizes to the micron range and increasing densities to 99% or so. In addition, the following main mechanisms for crack retardation are applied (Ref. 1.4):

(a) Transformation-toughened ceramics (such as partially stabilized zirconia [PSZ]) contain dispersed small particles of a metastable phase (e.g. Y_2O_3, MgO in the case of PSZ) that transform crystallographically when the strain field of crack passes through or near them. In this way, some of the energy of the crack is absorbed. If the transforming particles also increase in volume, they can apply a compressive stress to the crack tip, reducing its effective driving force;

(b) A second way to stop a crack is by spreading the stresses concentrated at its tip over a larger surface. This can be accomplished if minute cracks (called microcracks) are purposely created in the ceramic material during processing;

(c) Thirdly, ceramics can also be made crack-resistant by interlacing with fine fibres or whiskers, as is the case in composite materials.

The operational life of structural industrial ceramic components must be predicted with a probabilistic approach, i.e. a combination of data obtained from Weibull statistics and fracture mechanics calculations. If reliability data (operating life at maximum loading) are necessary for a structure composed of a number of components, Weibull curves must be coupled to stress distribution studies.

One of the oldest industrial applications of ceramics is in cutting tools. The conventional solution has been to use steel or carbide tools with a wear-resistant surface of, say, titanium nitride, titanium carbide, aluminium oxide or a combination of two or more of these. Still greater grinding performance can be obtained by using much more expensive materials—the synthetically produced cubic boron nitride and man-made diamond.

High-temperature applications of technical ceramics—in which properties such as good thermal shock resistance and the relatively excellent resistance to corrosion of some materials are important—have been at the forefront of attention for many years. Ceramics in internal combustion engines, gas turbines and high-temperature heat exchangers hold the greatest imaginative appeal. A number of technological and cost problems, however, must be solved before the full potential of advanced ceramics can be realized in the market-place. A list of new products made of advanced structural ceramics already being used in automobiles is given in table 1.1.

1.3.3. *Polymers*

The major polymers can be broadly divided into (a) the thermoplastics, whose polymer chains are not chemically bonded to each other and can be melted or softened by the application of heat, (b) the thermosets, whose polymer chains are bonded chemically, producing a three-dimensional network that cannot be melted by heating, (c) the elastomers or rubbers, which can deform elastically by several hundred per cent.

Polymeric materials are increasingly being used as replacements for metals in existing industries and for completely new products in emerging industries. Their attractiveness is due

Table 1.1. EXAMPLES OF STRUCTURAL CERAMICS CURRENTLY USED IN AUTOMOBILES

Component	Material
Mechanical seal for water pump	Al_2O_3
Catalyst pelleted support	Al_2O_3
Catalyst monolithic support	$MgO - Al_2O_3 - SiO_2$
Fibre for FRM piston	$Al_2O_3 - SiO_2$
Heat insulator for catalyst	$Al_2O_3 - SiO_2$
Glow plug for diesel engine	Si_3N_4
Precombustion chamber for diesel	Si_3N_4
Rocker arm tip	Si_3N_4
Turbochargers	SiC, Si_3N_4

largely to the ease with which they can be formed into complex shapes at only modestly high temperatures by injection moulding. For general engineering use, polymers have two major deficiencies: lack of stiffness and poor elevated-temperature properties when compared with metals; the maximum operating temperature for the best heat-resisting thermoplastics is about 300°C. However, in recent years new grades of polymers with a new price/performance ratio which have the ability to tailor materials have been developed by combining materials: polymer with polymer, polymer with elastomer, polymer with inert fillers and reinforcement.

The tensile strength and elastic modulus of crystalline and glassy polymers are comparable to those of wood (see figure 1.1). The specific strength (i.e. strength/density) is comparable to that of steel. Both the tensile strength and the elastic modulus may be increased by drawing crystalline polymers into fibres, whereupon their mechanical properties become comparable to those of aluminium alloys. The drawing process unfolds the molecular chains which become aligned in the drawing direction; and the fibre reflects the superior properties along the axis of the molecular chains. Examples of high strength fibres are:

(a) Polyethylene fibres may be drawn to give an elastic modulus of about 150 to 250 GPa and a strength of about 3.5 to 7.0 GPa; however, they still melt below 150°C;

(b) Carbon fibre, produced by heating and carbonizing drawn polyacrylonitrile, has an elastic modulus of about 200 GPa and a strength of about 1.5 GPa. Treatment in argon at 1700°C increases the strength to about 3 GPa, and annealing at 2600°C can increase the modulus up to 400 to 600 GPa;

(c) Kevlar fibre (diameter ca. 7 μm) is a polyaramid in which the molecules consist of amide and carbonyl groups separated by rigid pheylene rings. The fibres have an elastic modulus of about 30 GPa (which may be increased to 70 GPa by annealing at 400°C) and "as-spun" strengths of about 2.5 GPa up to several hundred degrees Celsius.

The main advantage of thermoplastics for engineering applications are: ease of shaping (pressing, injection moulding, extrusion, thermoforming, etc.), low density (about 1g/cm^3), toughness comparable with metals (see figure 1.1) and orientability (fibres, biaxially strengthened films, tapes, etc.). In addition, the good chemical resistance of, e.g. polyethylene, polyvinylchloride and polypropylene make them useful for domestic piping, drainage and rainwater goods, etc.

Filled thermosets, such as polyester and vinyl esters, which are established polymers of recognized stability in the marine and chemical industries, are now finding a variety of uses, both structural and decorative, in building. In addition, plastic foams (from thermosets or thermoplastics) are finding increasing applications for structural proposes. These fine-celled foams are sufficiently rigid and strong to bear modest loads (e.g. panels, furniture), even tough and flexible ones designed for shock absorption.

Polymer blending, which was first applied in order to increase the toughness of brittle amorphous polymers, such as polystyrene, polyvinylchloride and polymethylmethacrylate, is now routine. In a glassy polymer combined with a relatively small proportion of an elastomer, the rubber particles toughen the material by enabling it to absorb energy more efficiently as it is fractured. Recently, a new class of immiscible blends has been developed—the so-called "high performance" blends—incorporating several components, e.g. polycarbonate with polybutylene terephthalate. Because neither polymer is the dominant component, the two phases exist in an intricate interpenetrating network. The blend's resistance to heat and solvents is higher than pure polycarbonate, and its durability makes it a candidate for the replacement of metal in automotive components such as bumpers.

At present, an appreciable proportion of all polymers produced becomes waste within a few months. In view of the consequences of this for the environment, there is now considerable pressure and incentive to find ways of recycling such materials.

1.3.4. *Composites*

Composites are intimate mixtures of two or more materials chosen with the aim that the resulting properties of the composite mixture are superior to those of its individual constituents. For structural purposes the objective is to increase strength and rigidity, perhaps simultaneously reducing density. The vast majority of composites are those in which fibres serve as reinforcement, such as glass fibres, carbon fibres, boron fibres, alumina fibres. Promising (but very costly) new fibre materials are rapidly solidified fibres with amorphous or microcrystalline structures and metal or ceramic single crystal whiskers grown specifically to contain very low dislocation densities and 180° thus very high yield strengths.

The main composite systems are (Ref. 1.2):

(a) Fibre-reinforced plastics, initially based on the thermoset plastic moulding materials, polyester, epoxy, phenolic or silicone resins, with various reinforcements, mainly glass, carbon or Kevlar fibres. They provide strong, low density and easily fabricated materials for structural purposes and a maximum working temperature of about 180°C. Thermoplastics (injection-moulded) are also being used as matrix materials. In load-bearing applications, a polyamide matrix gives the best overall mechanical performance in terms of strength and modulus over a fairly wide temperature range. Compounds based on polyethersulfone (PFS) and polyetheretherketone (PEEK) are suited for applications where higher temperature performance is required. Carbon-fibre reinforced plastics are beginning to appear in engineering in applications where weight saving is at a premium;

(b) Fibre-reinforced metals assumed to improve the high-temperature performance of nickel and titanium matrices by incorporation of tungsten and carbon or boron fibres were not successful because of problems such as inter-diffusion and oxidation damage. Much of the development work on metal matrix composites is now concentrated on low-temperature systems, mainly based on carbon or boron fibres in aluminium. The merits of these systems are good tensile strength, elastic modulus and compressive strength, both parallel and normal to the fibres, relatively high impact strength and fracture toughness, high specific strength, high softening temperatures and ease of joining by welding, brazing or diffusion bonding;

(c) Fibre-reinforced ceramics are suited, in principle, for temperatures above those at which a metal matrix can serve. Ceramic materials for the matrices cover a wide range, including silicon carbide, silicon nitride, aluminium oxide or mullite and zirconia. Fibres of the same of other materials are embedded within the matrix to produce the composite. Many believe that composites are the best route to wide applications of ceramics as structural materials. Carbon-carbon composites retain much of their strength up to 2500°C; they are used in the nose cone of re-entry space vehicles. Unlike most ceramic-matrix composites, they are vulnerable to oxidation at high temperatures, so a thin layer of ceramic is often applied to the surface to protect it;

(d) Fibre-reinforced cements with matrices of the stronger low-porosity macro-defect-free (MDF) cement (see section 1.5.1), reinforced with fibres derived from glass, polypropylene, cellulose, amorphous metal ribbon, and stainless steels are receiving a great deal of attention. They are of interest both from a structural engineering point of view and for health and safety reasons as replacement for the asbestos-filled cement traditionally used in building for roofing, gutters, pipes, etc.

1.4 *Functional materials*

The term "functional materials" denotes classes of materials which are used in various branches of industry because of their specific functional properties—for example, electric, magnetic or optical properties. They play an enabling role in some of the key techno-economic areas such as the electronics industry or in contemporary information technology (Ref. 1.8). The field of functional materials is extremely broad; only a few general trends can be discussed within the scope of this study.

1.4.1 *Electronic materials*

The increasing complexity of electronic systems is forcing semiconductor technology to very large scale integrated (VLSI) circuits. This requirement for microminiaturization will require the development of new techniques for etching ever finer features onto a chip; some promising approaches include the use of electron beams and X-rays rather than visible light to define the circuit pattern. Newer chip designs and newer chip materials are moving beyond the limits of silicon, leading to the proposal of three-dimensional chips (in which circuit components are arranged in stacks rather than single layers on a chip's surface) and to the application of gallium arsenide. Transistors made from gallium arsenide could have two to five times the switching speed of silicon transistors, leading to faster and more powerful computers.

A key to the continued progress in VLSI technology is the refinement and development of new materials characterization tools. Structural defects such as dislocations and stacking faults play an important role in determining the electron properties of semiconductors. Thus, continued development of high-resolution electron microscopy techniques is important, in conjunction with the development of other methods for "imaging" the properties of materials.

Plasma-assisted deposition of conductors, insulators and barrier layers is common practice in semiconductor manufacturing. Molecular beam epitaxy (MBE) offers precise control of layer thickness and will be important for high-speed devices, as well as for semiconductor lasers and integrated circuits. Advances in the complexity of integrated circuits place demands not only on the semiconductor materials themselves but on a variety of materials associated with the chip and its "package".

An important class of materials for electronics applications nowadays are ceramics. The chemical compositions, crystal structures and the function and application of many new electronic ceramics are summarized in table 1.2.

1.4.2 *Magnetic materials*

"Soft" magnetic materials (originally, simply iron) are used most widely in transformer applications where low energy loss is desired. Special grain-oriented silicon steels have been developed over the past 50 years to provide lower losses than ordinary irons or steels. However, new metallic glasses made by the rapid-solidification process exhibit only one twentieth to one third the core loss of the best steels available.

There have also been recent major advances in "hard" magnetic alloys—alloys that can be magnetized to a high value and retain that magnetism. Figure 1.4 shows how the "energy product" of permanent magnets has improved over the past decades (Ref. 1.8). These new materials have contributed to the design of advanced electric motors, generators, actuators and electro-acoustical devices, for example.

For magnetic storage media—which are essential for contemporary information technologies—two distinct types of materials are in use today: particulate—in which the magnetic ingredient consists of submicroscopic, single-domain particles of oxide or metal immersed in a polymeric binder—and thin films of ferromagnetic metals and alloys.

1.4.3 *Superconductivity*

Of great current interest are the high-temperature superconducting perovskites (for example Ba-La-Cu-O and Sr-La-Cu-O). These were first shown to be superconducting in 1986. Superconducting transition temperatures in excess of 90°K were confirmed early in 1987.

Table. 1.2. EXAMPLES OF CERAMICS FOR ELECTRONICS APPLICATIONS

Crystal Structure	Chemical cmposition	Function and application
	$BaTiO_3$, $SrTiO_3$, $CaTiO_3$	Capacitor
	$Ba[Zn_{1/3}(Nb,Ta)_{2/3}]O_3$,$(Sr,Ca)[(Li_{1/4}Nb_{3/4}),Ti]/O_3$	microwave dielectrics
	$Pb(Ti, Zr)O_3$,$Pb[Mg_{1/3}Nb_{2/3})$, Ti, Zr]O_3	piezoelectrics
Perovskite type	$PbTiO_3$	pyroelectrics
(ABO_3)	(Pb, La) (Ti, Zr)O_3	electrooptics
	(La, Sr)CoO_3	heater
	Ba(Pb, Bi)O_3	superconductor
	(Mn, Zn)Fe_2O_4	soft ferrite, magnetic head
Spinel type	$CoFe_2O_4$	memory ferrite
(AB_2O_4)	(Mn, Cu) (Mn, Co, Ni)$_2O_4$	thermistor
	Mg[Al, Cr Fe]$_2O_4$, $CoAl_2O_4$, $NiAl_2O_4$	high-temp. thermistor

Figure 1.5 shows the remarkable increase of achievable transition temperature in superconducting materials since their first discovery in 1911 (Ref. 1.8).

There is hope that even higher transition temperatures will be achieved; there is also the expectation that current-carrying capacity will be great enough for practical devices and conductors, and that the pertinent materials can be fabricated in a suitable manner.

1.4.4 *Photonics*

There is increasing interest in expanding the possibilities of information technologies by using photonics devices. In a photonic system, information is carried by pulses of light. The light source is a semiconductor laser or a light emitting diode, and the transmission medium is a hair-thin fibreguide or silica glass. Light pulses (and thus information) can be transmitted through optical fibres at a rate much higher than the pulse rate of electrical signals sent through coaxial cables.

Photonics owes part of its remarkably rapid progress to advances in laser technology. The most effective lasers utilize compound semiconductors such as indium-gallium-arsenide phosphide. Also, glass can now be made so pure and transparent that a light signal can travel for hundreds of kilometres before it has to be reinforced.

Glass is also displacing copper as material for telephone cables: optical-fibre guides now account for about one third of the growth of the "feeder routes" that carry telephone channels from central offices to clusters of users.

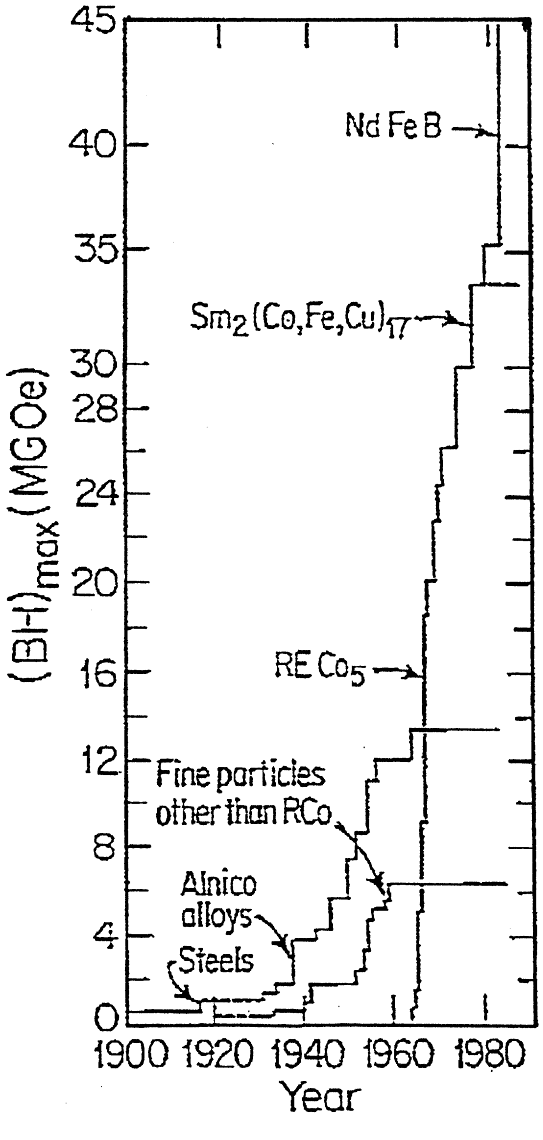


Figure 1.4. DEVELOPMENT IN HARD MAGNETIC MATERIALS SINCE 1900

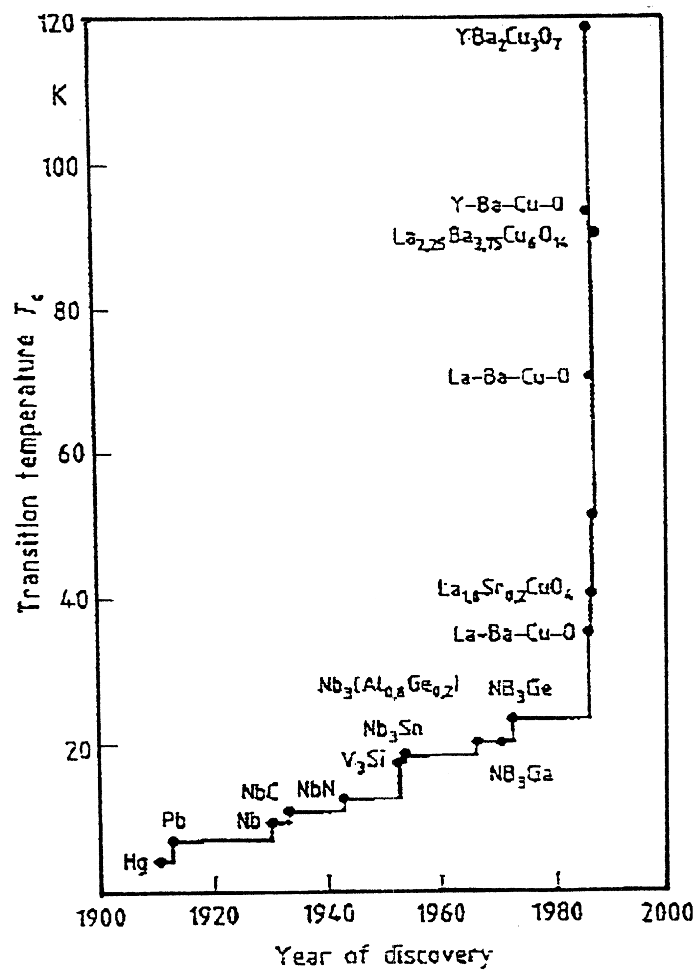


Figure 1.5. TRANSITION TEMPERATURES IN SUPERCONDUCTING MATERIALS FROM 1911 TO THE PRESENT

1.4.5 *Sensors*

Another area of application of functional materials is in sensing devices. Examples of modern sensors are ceramics, which change their electrical properties when exposed to specific gases or other substances. The chemicals reversibly change the ceramics' electrical resistance, and sensing devices can be constructed based on that principle. The non-reactivity and corrosion resistance of ceramics allow sensors made from these materials to perform with considerable effectiveness in harsh chemical environments—for example, in measuring exhaust contaminants in internal combustion engines. Table 1.3 lists examples of ceramic sensors.

1.5 *Civil engineering materials*

Despite their long history, civil engineering materials, such as cement, concrete and plaster, are the subject of continuous application-oriented research and development which is creating materials with new and improved properties to meet the demand for new buildings, housing, roads and bridges (Ref. 1.9).

1.5.1 *Cement*

Portland cement (annual world production: 800 million tonnes), the "glue" in the most widely used composite material concrete, is a typical example of "low-technology" ceramics. For acceptance as a more general engineering material, attempts have been made to increase the fracture strength by reducing the flaw size (according to Griffith's fracture criterion). Reducing

Table 1.3. EXAMPLES OF CERAMICS SENSORS

porosity and pore size, the so-called Macro Defect Free (MDF) cement with considerably improved mechanical properties has been developed (unnotched bend strength of 150 MPa) and is comparable with the strength of aluminium and polymers such as PVC. It is possible that the new MDF cement may, in some cases, provide cheap substitute materials for metals and polymers, not only because of improved strength but also because of its relatively low density (2.5 g/cm^3), stiffness (elastic modulus of 50 GPa), corrosion and heat resistance, low thermal conductivity, good acoustic damping, and ease of moulding (and colouring).

1.5.2 *Concrete*

Concrete (annual world production 7,000 million tonnes or 3,000 million m^3) is an artificial stone made from cement, sand and various kinds of aggregate, such as gravel. It has high compressive strength (10 to 100 MPa) but is brittle in tension (flexural strength 3 to 8 MPa) and cracks readily. Many possibilities exist for modifying the properties of concrete—for example, by using admixtures to control the setting rate or to prevent bleeding and shrinkage; by using plasticizers to improve workability; by incorporating various polymers in the fresh concrete, and by reinforcing, using fibres of various materials, such as steel, glass, polyamide, polypropylene, Kevlar, or carbon or natural fibres. Polymer impregnated concrete can be made with strength well above those of conventional concrete (for example, strengths of 15 to 25 MPa, elastic modulus of 40-50 GPa), but at a considerable premium in terms of direct materials cost and energy. The wide range of materials that can be used in modern concrete technology is shown in table 1.4 (Ref. 1.9).

1.6 *Renewable materials*

The most economically important renewable resources and the recycling materials based on them are wood, waste paper and straw. In the industrialized countries, the consumption of sawn timber products is stagnating at a relatively high level, while the consumption of wood-based materials—plywood, fibreboard, particle board and articles moulded from fibres or chips—is rising steadily. Figure 1.6 demonstrates this trend in Western Europe (Ref. 1.10).

The dwindling global supply of roundwood, caused by the devastation and over-utilization of forests and the effects of pollution, will precipitate an increased use of smaller-diameter wood in the future. The greatest disadvantage of smaller woods— its high proportion of knots—may be compensated for by new technologies.

Solid wood panels may be glued with splines to form long elements (gluelam technology). Also, new types of panels with improved properties are being developed. For example, the oriented structural board (OSB) technology uses special chips or strands which are oriented by special equipment to manufacture a product whose strength is comparable to that of clean solid spruce of the same specific gravity. Based on technological developments and economic considerations, the following trends in utilizing renewable resources may be outlined:

(a) The substitution of solid wood by wood-based materials will increase;

(b) The panel industry will be able to utilize the growing amounts of smaller wood by applying specific technologies;

Table 1.4. MATERIALS USED IN CONTEMPORARY CONCRETE TECHNOLOGY

Binder systems	Aggregates	Reinforcing systems	Admixtures
Portland cements	Natural sands and gravels	Ordinary steel bars	Additives -- for examples, retarders, accelerators, stabilizers, air-entraining agents, workability aids, water-reducing agents
Blended cements	Crushed aggregates	Wire mesh, glass fibres, steel fibres, polymer fibres	Fly ash, silica
Special cements (with or without admixtures)	Natural light aggregates	Special-purpose steel bars and steel cables	Polymer dispersions, epoxy resins, emulsions
Cementitious materials, mostly reacting with water	Pyro-processed lightweight aggregates	Pre-stressing systems	
	Natural heavy aggregates	Glass fibre tendon systems	
	Inorganic and organic wastes		
	Special inorganic and organic products		

(c) The production capacities of plants utilizing small-diameter wood will increase;

(d) Wood-based materials will be improved by the use of a variety of special resins.

1.7 *Biomedical materials*

Materials of various kinds have been used to "repair" the human body when accidents, war, illness or congenital defects prevent an organ from fulfilling its given function (Ref. 1.11). For example, prostheses have become a significant economic sector with a worldwide market of more than $2.3 billion in 1983 ($1.3 billion in cardiovascular prostheses and $900 million on orthopaedics, representing the two major areas). The output in medical and surgical equipment and orthopaedic appliances in the European Economic Community amounted to ECU 5.5 billion in 1988.

In examining prostheses, three criteria arise:

(a) Aesthetic and social acceptability;

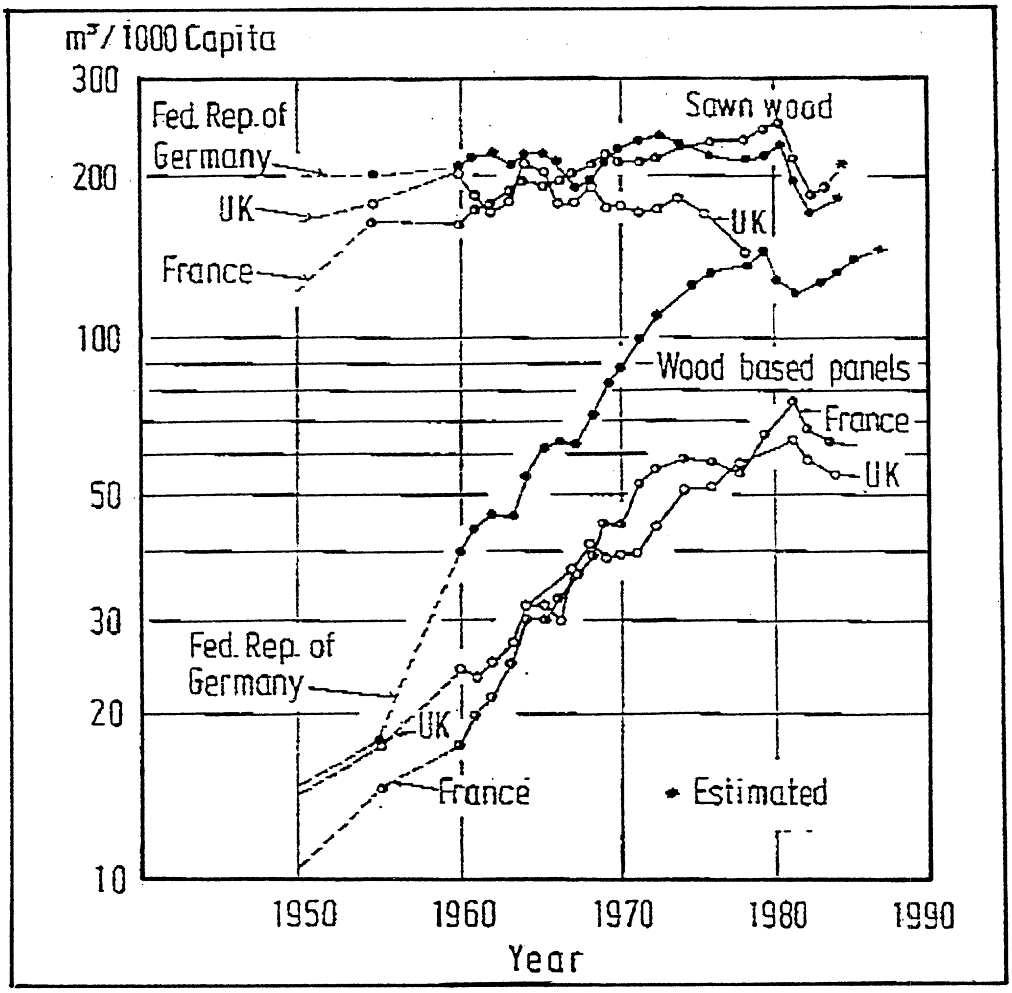


Figure 1.6. CONSUMPTION OF SAWN TIMBER AND WOOD-BASED PANELS IN WESTERN EUROPE

(b) Biocompatibility, in the sense of a prosthesis not harming the host tissue (non-toxicity; lack of rejection);

(c) Biofunctionality, or mechanical and corrosion resistance, which allows prostheses to fulfil their functions for extended periods without alteration.

For biomedical materials and components in general, two essential elements of the subject should be noted. The first element concerns the rivalry between two apparently different modes of approach: on the one hand, the possibility of transplanting tissue or a living organ; and on the other hand, the attempt to find a biocompatible, biofunctional material. The second alternative concerns the development of biomaterials. These materials are of several types: they may have the same structure as bone and would thus be prone to gradual colonization by bone cells; they may be biodegradable materials which encourage cell growth before disappearing completely; or they may simply be inert materials with exceptional properties not likely to cause side-effects. Table 1.5 gives an overview on major biomaterials and their primary uses (Ref. 1.2).

2. *Industrial and materials research and development trends and needs in Europe*

In order to determine on a broad basis R&D needs in industrial and materials technologies, an inquiry was made in the countries of the European Economic Community (Ref. 2.1). A questionnaire was developed and sent to about 700 institutions (industries, universities and research organizations) in all EEC countries. The questionnaire contained the following questions:

What are the prime important R&D requirements in the fields of:

1. *Materials and properties?*
2. *Design?*
3. *Manufacturing and processing?*
4. *Performance needs?*
5. *Testing and evaluation?*
6. *Other (e.g. crucial operating conditions, environmental impact, recycling, quality assessment)?*

Responses to a questionnaire by main industrial, technological and scientific sectors reflect the following distribution:

Industry:	70%
Universities:	24%
Research organizations:	6%

A computer programme was used for the evaluation of the information presented in the answers to the questionnaire. A total of 3,010 entries were fed into the computer, and the distribution of answers with respect to the following eight basic groups was determined:

I. Industries interested in R&D
II. General tasks for R&D in industrial and materials technologies
III. Products characteristics suggested for R&D
IV. Materials suggested for R&D
V. Materials properties suggested for R&D
VI. Design techniques suggested for R&D
VII. Manufacturing and processing technologies suggested for R&D
VIII. Testing and assessment techniques suggested for R&D.

2.1 *General tasks for R&D in industrial technologies*

Results of the computerized analyses of the questionnaires were obtained in the form of diagrams characterizing the distribution of answers in the eight areas mentioned above. In addition, keywords for R&D needs and suggestions were compiled. An overview on general

Table 1.5. BIOMATERIALS AND THEIR MAJOR USES

Material	Major users
Metals and alloys	
316 stainless steel	orthopaedic fracture plates, joint replacement prostheses
Cobalt-chromium alloys	orthopaedic fracture plates, joint replacement prostheses, denture bases, heart valves
Titanium and its alloys	orthopaedic fracture plates, dental implants, cranial plates
Platinum metals	electrodes
Plastics, elastomers, and fibres	
Polymethylmethacrylate	dentures, cement for fixation of orthopaedic prostheses, ophthalmic implants and contact lenses
Polydimethylsiloxanc	soft-tissue reconstruction (e.g. breast, facial contours), finger joint prostheses
Polyethylene	joint replacement prostheses
Polypropylene	finger joint prostheses, heart valves, sutures
Segmented polyurethane and natural rubber	blood-compatible materials for artificial hearts
Polyethylene terephthalare and fluorocarbon polymers	arterial prostheses, heart valve sewing rings, meshes for soft-tissue reconstruction
Hydrogels	blood-compatible surfaces, ophthalmic prostheses
Polylactic and glycolic acids	absorable sutures and degradable prostheses
Cyanoacrylates	adhesives
Ceramics and glasses (largely experimental)	
Oxide ceramics (e.g. alumina)	joint replacement prostheses
Ion-leachable glasses	dental cement, coating for orthopaedic prostheses
Carbons	heart valves, dental implants, percutaneous implants

R&D tasks is given in figures 2.1 to 2.3.

Figure 2.1 indicates that a broad spectrum of industrial branches is interested in R&D in industrial and materials technologies, namely

Chemical industries
Electrical engineering
Mechanical engineering
Motor vehicles
Aerospace
Civil engineering.

Other specific industries—which contribute to about 50% of the responses of the questionnaires—were summarized under the general term "engineering industries".

The general tasks which have been named by the various industries as priority themes for research and development in industrial and materials technologies are summarized in figure 2.2. Three quarters of all answers are related to the following topics of overall (medium-term) importance:

Cost reduction
Environment compatibility
Energy and materials savings.

For the industrial products which may result from intensified R&D, the following topics are of paramount importance (response of about 80%) as can be seen from figure 2.3:

Recycling aspects
Long-term performance
Functional purpose.

2.2 *Materials and materials properties suggested for R&D*

In the field of materials, the main interest is in composites (30%), followed by ceramic materials (20%), metals and alloys (19%) and polymers (17%) (see figure 2.4). The main materials properties suggested for R&D are compiled in figure 2.5.

With respect to materials and materials properties suggested for future R&D in Europe, a large variety of details was given in the questionnaires. For the main classes of materials mentioned above, the themes which correlated in substance are listed below in an approximate order of importance.

2.2.1 *Composites*

For the present purpose, it is reasonable to subdivide the entries for the total class of composites (100%) into those for polymer matrix composites (47%), metal matrix composites (15%) and ceramic matrix composites (7%). The remaining percentage is attributed to concrete composites and other general entries which have not been specified. In detail, the following

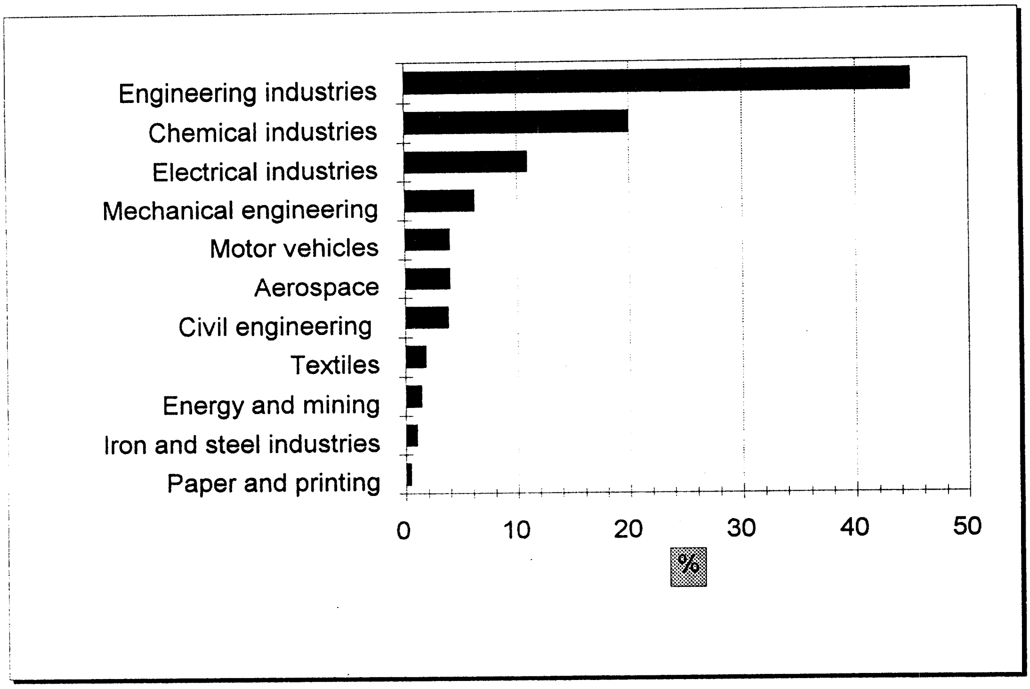


Figure 2.1. INDUSTRIES INTERESTED IN RESEARCH AND DEVELOPMENT
(928 entries = 100%)

themes are of interest:

(a) *Polymer matrix composites (PMC)*

- High-temperature performance
- Increased stiffness and low density
- High strength and fracture toughness, improved damage tolerance and compressive properties
- Improved resistance against aggressive agents.

The following types of PMC have been mentioned for special interest:

- Thermoplastic matrix composites
- Composites with short fibre and sub-nm reinforcement as well as those in the molecular range
- Composites with whisker reinforcement
- Composites for low-temperature processing.

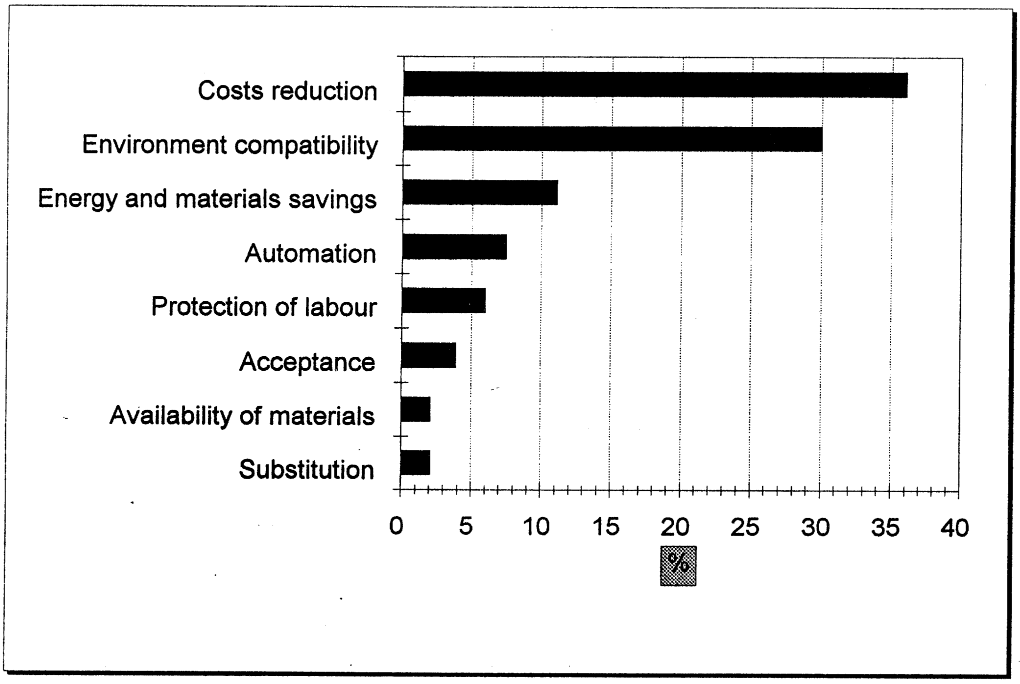


Figure 2.2. GENERAL TASKS FOR RESEARCH AND DEVELOPMENT IN INDUSTRIAL AND MATERIALS TECHNOLOGIES
(130 entries = 100%)

Additional indications with respect to an improvement of the mechanical properties are expected from investigations on the effects of fibre alignment as well as on the fibre-matrix interface properties, e.g. the debonding effects.

(b) *Metal matrix composites (MMC)*

Prominent themes are:

- Al-matrix composites with ceramic fibres; upgrading of strength and stiffness;
- Compounds with a combination of high strength and good corrosion resistance;
- Compound materials and structures with special properties.

Again, the effect of fibre alignment on the mechanical properties is of interest.

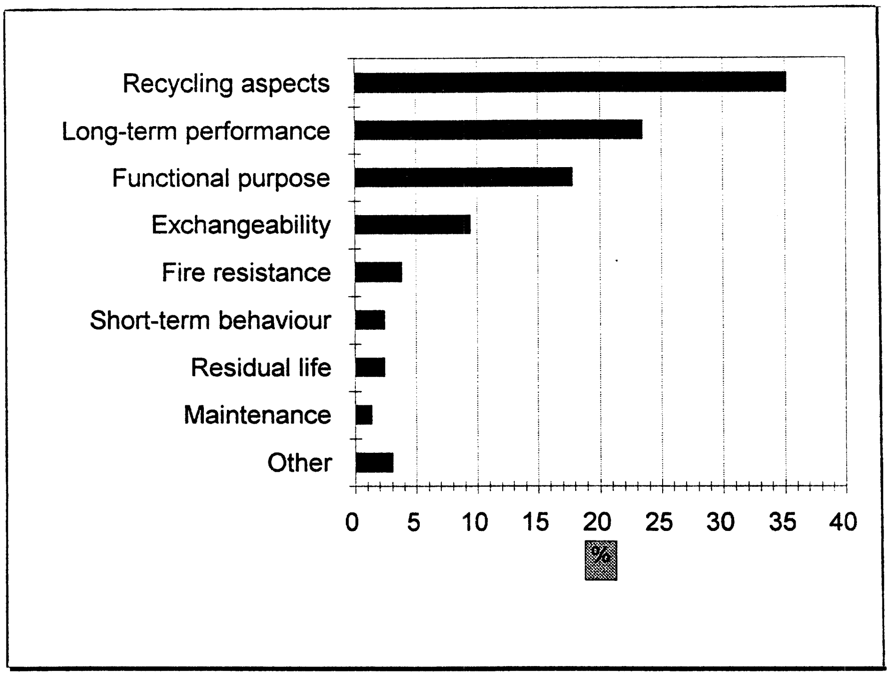


Figure 2.3. PRODUCT CHARACTERISTICS SUGGESTED FOR RESEARCH AND DEVELOPMENT
(156 entries = 100%)

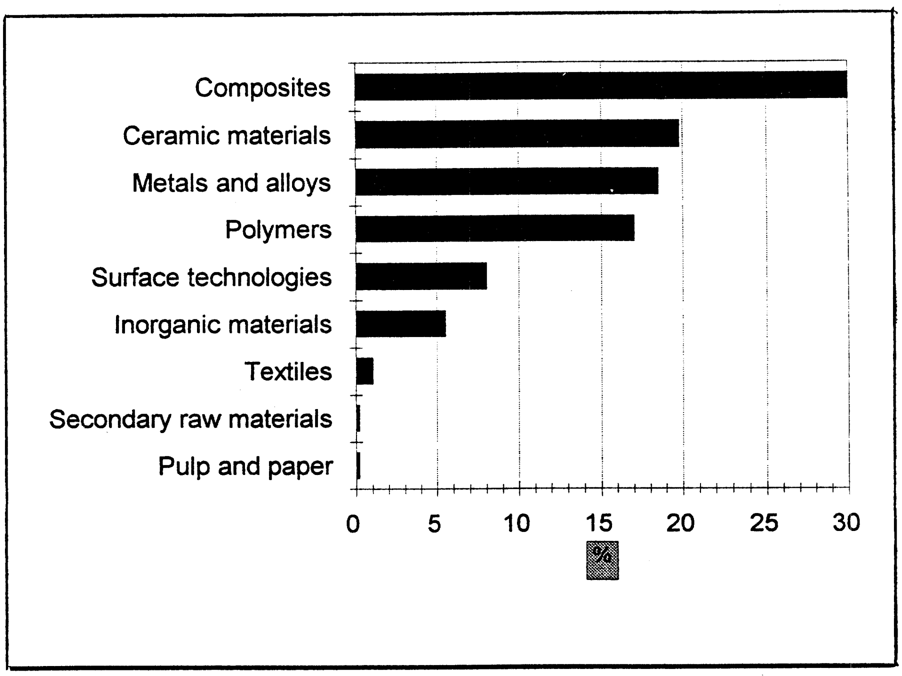


Figure 2.4. MATERIALS SUGGESTED FOR RESEARCH AND DEVELOPMENT
(596 entires = 100%)

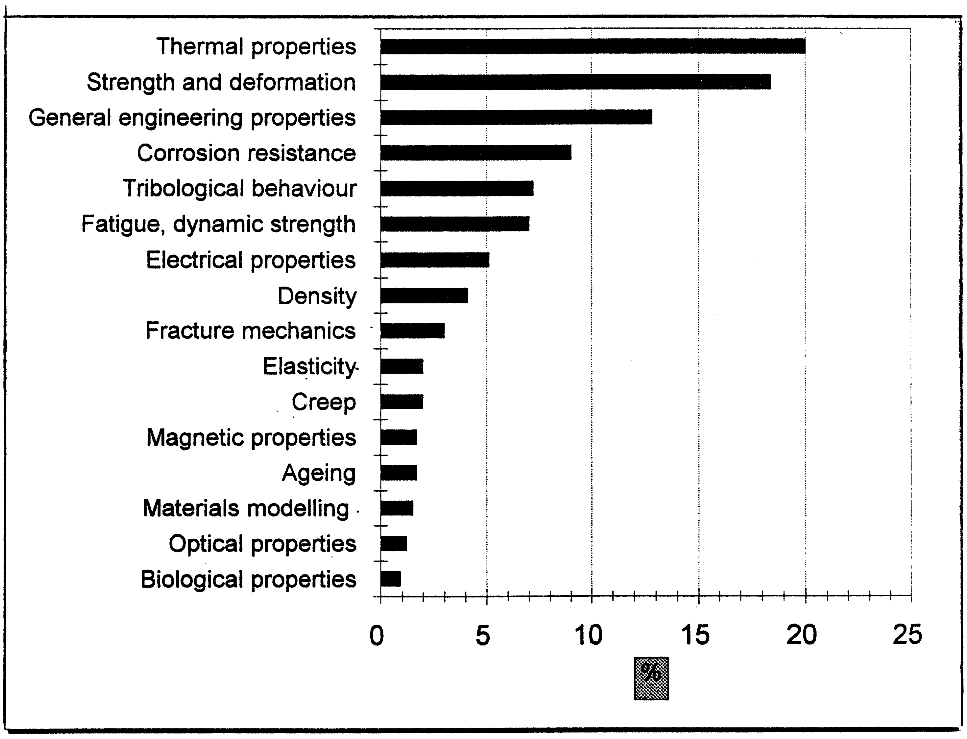


Figure 2.5. MATERIALS PROPERTIES SUGGESTED FOR RESEARCH AND DEVELOPMENT
(383 entries = 100%)

(c) *Ceramic matrix composites (CMC)*

Themes of special interest are:

- Resistance against high temperature and chemical attack and;
- An upgrading with respect to strength, fracture toughness and damage tolerances.

Of further interest are the reinforcement with whiskers and other short fibres as well as the effect of the fibre alignment and that of the interface properties on the debonding of the fibres.

2.2.2 *Ceramics materials (monolithic engineering ceramics)*

For the class of monolithic engineering ceramics, an upgrading with respect to the following aspects is of general interest:

- Strength in general
- High-temperature properties with respect to strength, creep Resistance and inhibition of grain growth
- Brittleness and fracture toughness
- Fatigue strength
- High temperature corrosion resistance
- Resistance against chemical attack
- Tribological behaviour (friction, wear)

Out of the variety of engineering ceramics, the class of non-oxide ceramics (SiC, Si_3N_4, B_4C, BN) seems to be of special interest, whereas the necessary improvement of the reliability of ceramic structures in general leads to agglomerates (< 1 nm) as a basic material for engineering ceramics. In this context, the surface chemistry of the powders and the manufacturing and application of "nano-materials" is discussed.

Further ceramic materials of interest for R&D activities are:

- Functional ceramics with special electrical, magnetic and optical properties
- Ceramic coatings
- Glass and glass ceramics with respect to an upgrading of strength and toughness
- Refractories for melting furnaces, etc.
- CERMETS (ceramic/metal compounds).

As a general R&D theme, the development of proper constitutive models for the deterioration mechanisms of brittle materials was recognized.

2.2.3 *Metals*

Of special interest for R&D activities are those metallic materials which promise further upgrading of the high-temperature behaviour (strength, creep resistance, high-temperature corrosion resistance) for application in, *inter alia*, gas turbines, jet engines and chemical processing, interest was expressed in the following:

- High-temperature steels;
- High-temperature superalloys of the polycrystalline, directionally solidified and single crystal types;
- Mechanically alloyed (MA) Ni-base alloys;
- Intermetallics, e.g. of the Ni-Al-type for high-temperature application;
- Ti-alloys for the medium temperature range;

Further activities are desired with respect to an upgrading of low-density metals such as:

- Mechanically alloyed Al- and Ti-alloys (strength at higher temperatures)
- Al-Li-alloys for the aircraft industry (density, stiffness)
- Li-alloys (extreme low density).

Furthermore, nanocrystalline metals and amorphous alloys manufactured by rapid solidification techniques are suggested for further research.

For a plurality of conventional materials, an improvement is requested, especially with respect to economic effects and competitiveness:

- Micro-alloyed steels with respect to an enlargement of the field of application and acceptance in regulations
- Cast metallic materials by advanced processing routes; easy recycling
- Austempered nodular cast iron
- Duplex-structure stainless steels
- Materials and structures via powder metallurgy routes; higher relative density
- Metals with superplastic properties
- Magnetic alloys with minimized losses.

Finally, further research on the correlation of microstructure and mechanical properties has been recognized as a general future task.

2.2.4 *Polymers*

For the class of polymers and polymer blends, one of the main themes of interest for R&D is focused on the upgrading of their properties at higher temperatures:

- Flow (creep) resistance at elevated temperature;
- Thermal resistance (e.g. at soldering temperatures);
- Hydrothermal stability;
- Thermal conductivity;
- Fire resistance without use of halogenated compounds.

Importance is also attributed to the electrical conductivity—especially reversible (switch on/off)—as well as to low electrical charging. Strength and toughness are generally upgrading candidates for polymers. Other properties of special interest are:

- Chemical endurance and resistance against aggressive agents
- Low coefficient of friction and high wear resistance
- Special optical properties.

Good biological degradability and recycling properties are of vital importance for future application of this class of materials.

R&D activities are necessary also for polymer biomaterials (engineering inside the body). With respect to the application "tailor-made" materials with suitable mechanical properties, no degradation inside the body and no release of toxic monomers are required.

Different properties are important for polymer materials, which are optimized with respect to an application in the textile and shoe industry. Low density, high damping capacity and wear resistance as well as special porosity are required here.

2.2.5 *Other materials*

In addition to the R&D topics with respect to the four main classes of materials, suggestions for R&D concerning other types of materials have been made as outlined in the following:

- **Materials for information technologies:** microelectronics, circuit boards; materials with integrated optics; high purity materials of special composition for computer technology; substrates for thin coatings; semiconductors with diamond structure.

- **Coating materials:** coatings made from hard materials (wear resistance), ion implantation, laser hardening; sputtered thin coatings for computer technology, impact-resistant coatings; functional coatings of high surface performance and corrosion resistance.

- **High-temperature superconductive materials (HTS):** applications for energy technology (coils, magnet, etc.); high critical current density; compound systems of HTS ceramics on metallic substrates; processing of HTS powders to wires.

- **Materials for civil engineering application:** concrete with composite cements and polymer additives and fibre reinforced micro-concrete (glass and steel fibres).

- Carbon materials and carbon fibres for composite materials.

- Polycrystalline diamond with increased electrical conductivity and improved thermal properties; application for coatings.

- Materials for catalytic processes.

2.3 *Design techniques suggested for R&D*

For the area of design, the order of quantity of entries in the questionnaire is given in figure 2.6. It illustrates that material-related concepts are of great importance (50%), whereas computer-aided techniques (CAD, finite element calculations, expert systems, etc.) and general design rules are recognized as being of equal significance. In the following, the keywords again have been listed in an approximate order of importance.

(a) *Material-related concepts*

- Transfer of materials properties from specimens to components and structures; influence of geometry, down-sizing and up-sizing.

- Special design of components made out of short-fibre reinforced composites.

- Design of compound components; polymers combined with other materials. Advanced sandwich components and cellular structures with high stiffness.

- Design of micro-mechanical components using polymers.

- Design strategies with respect to brittle materials (ceramics); critical points of load introduction.

- Probabilistic approach to design; reliability models; distribution functions of material properties.

- Material flow calculations for improved design of metal forming moulds.

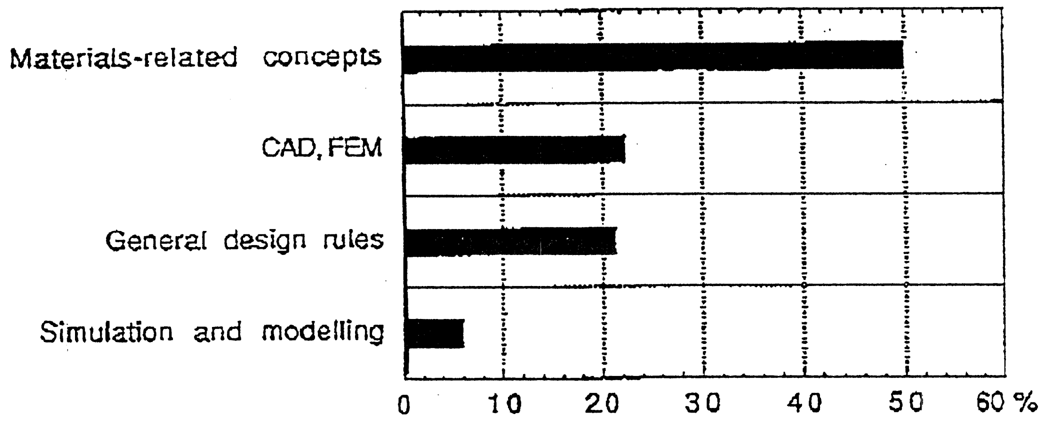


Figure 2.6. DESIGN TECHNIQUES SUGGESTED FOR RESEARCH AND DEVELOPMENT
(134 entries = 100%)

(b) *Computer aided techniques*

▶ Improvement of the efficiency of CAD as a basis for increased application; better adaptability of CAD systems.

▶ Application of finite element methods (FEM) for the assessment of strength, life time, and safety; use of material models for deterioration and failure.

▶ Improvement of the application of expert systems for the design and the assessment of lifetime and safety.

(c) *General design rules*

▶ Considering total life of components and structures, including defunctioning and recycling.

▶ Design with respect to manufacturing routes, mainly energy-saving processes.

▶ Design with respect to damage tolerance, maintenance, supervision, and quality control.

Especially in the field of high-temperature components, there is a need for improved material modelling which is compatible with the microstructure situation in a wide range of temperature and mechanical loading or deformation.

Other more special themes compiled from the questionnaires are:

▶ Low weight design with respect to the dynamic behaviour of components

- Design with respect to coating processes and coating performance
- Global service life assessment for building and components
- Seismic design in civil engineering.

2.4 *Manufacturing and processing technologies suggested for R&D*

In this field, 24% of the respondents suggested an improvement of general manufacturing technologies. Responses in 6-12% of the entries demonstrated interest in further R&D in conventional fields of manufacturing and processing technologies such as casting, forging, joining, forming, and machining. Similar percentages are related to some advanced technologies as computer integrated manufacturing (CIM), mass-production techniques, and powder metallurgy. A survey of the interests is given in figure 2.7.

Further research and development of manufacturing and processing technologies must be seen in connection with the pertinent materials or products. Therefore, the keywords out of the questionnaires are compiled with respect to the main material classes. Again, the details are listed in an approximate order of importance given by the number of entries.

(a) *Polymers*

In the field of forming, joining, moulding and other manufacturing techniques, the following details are of interest mainly with respect to economical effects:

- High-speed injection moulding with high accuracy; in this context, the rheology during mould charging is important.
- Miniaturization of injection moulding for small electronic structures.
- Electrochemical forming and machining; machining and laser cutting.
- Manufacturing of very thin structures and multiple layer structures.
- Deep drawing and stretch forming of polymers.
- Improvement of prepregging techniques; extrusion with prepregs.
- Three-dimensional fibre preforming.
- Rationalization by combination of chemical reaction and extrusion; reaction injection moulding for thermoplastic materials.

Some further problems with respect to manufacturing of polymer materials are:

- The gluing and snapping techniques

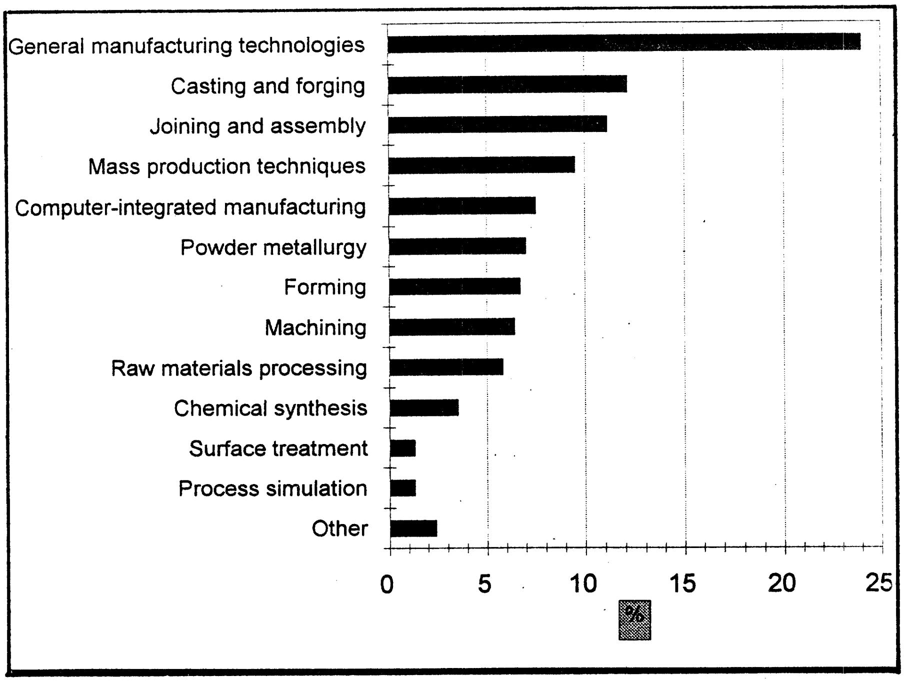


Figure 2.7. MANUFACTURING AND PROCESSING TECHNOLOGIES SUGGESTED FOR RESEARCH AND DEVELOPMENT
(294 entries = 100%)

- The improvement of rapid prototyping of components out of polymers.

Related to R&D activities in the field of synthesis and raw-material processing are keywords such as:

- Polycondensation techniques
- Electropolymerization
- Electrocoagulation
- Rheological processes in the molecular range
- Electrostatic deposition.

Of further interest are improved possibilities for recycling of thermoplastic composites to moulding processes.

(b) *Engineering ceramics*

For this class of material, the raw-material processing has a predominant effect on the resulting component properties. Some problems suggested for the future to R&D include the development of:

- Pure powders with narrow particle size distribution
- Sol-gel techniques
- Organo-metallic processes for powder production.

An upgrading of all joining techniques (ceramic-ceramic and ceramic-metal) also for high-temperature service is of vital importance to an increased application of ceramics.

Apart from that, the basic manufacturing techniques must be further developed. The following keywords give some detailed information compiled from the questionnaires:

- Wet forming techniques

- Optimized paste for extrusion and for injection moulding

- Economical sintering processes and sinter/HIP techniques

- Manufacturing routes for components free of internal defects

- Techniques for the production of ceramic-matrix composites with longer fibres

- Machining of ceramics.

(c) *Metals*

In the field of metals and alloys, conventional manufacturing processes such as casting, forging and metal forming are included in approximately half of all responses to the questionnaire and demonstrate the importance of a further improvement of these widespread techniques with respect to economic competitiveness. Next in the range of importance are mass production and CIM as well as powder metallurgy and joining problems. Out of the variety of keywords in the responses, the following have been selected:

- Die castings and injection die casting

- Continuous casting of thinner flat, bar and wire materials combined with rolling; near net shape casting

- Thin-walled extrusion

- Rapid forming techniques which result in special properties of metals

For metal matrix composites (MMC), casting techniques are of interest as well as forming and machining procedures which do not result in a deterioration of the materials. Low-cost, large-series processes for the manufacturing of MMC in general are open to further R&D efforts.

An upgrading of powder metallurgy was mentioned also, especially with respect to economic benefits. In this context, atomizing techniques of the base material are important with respect to the effect on the components.

A still important question is the effect of joining—especially welding—on the properties of components. Special welding techniques, e.g. diffusion and friction welding, are themes for further development as well as soldering techniques. Of special interest is safe welding for corrosion-resistant materials.

In the field of machining, the effect of material composition on the machinability and on the accuracy of the components was mentioned as interesting.

Finally, problems out of the field of rapid solidification techniques (RST) with respect to the manufacturing of powders, foils and wires with special properties have been mentioned in the questionnaires. Attributed to these "base materials" all possible techniques of compaction are themes for R&D.

(d) *Manufacturing problems in the field of civil engineering*

In this field, some details for further R&D have been compiled from the responses to the questionnaire which could be of general interest:

- Manufacturing of thin structures out of reinforced concrete by vacuum sucking
- Repair strategies for old/damaged structures
- Water jet pressure cutting of rock material
- Robotization of building techniques.

(e) *General manufacturing problems*

Some general problems, not related to special classes of materials, but more or less applying to the total manufacturing technology are partially included in figure 2.7 under the designation "general manufacturing technologies". Some of the problems in this field are characterized by the following keywords:

- Manufacturing process modelling
- Just-in-time manufacturing methods for mass production
- Processing with reduced environmental impact and low energy consumption
- General effects of manufacturing routes on the material and component performance

- Standardization of NC-control devices

- CIM with artificial intelligence

- Man-free production

- Tools of high wear resistance for long service life and high machining accuracy

- Advanced manufacturing techniques: e.g. fluid jet cutting, high-speed cutting, etc.

2.5 *Testing and evaluation*

In order to improve the competitiveness of industrial products and related technologies, advanced testing and assessment techniques are needed. As can be seen from figure 2.8, the main interest in this field is in techniques for quality control and non-destructive testing and evaluation (NDT). Another remarkable amount of interest was focused on R&D aimed at standardization of test methods and process control.

(a) *Materials-related aspects*

Most of the responses to the questionnaire were not related to special materials or products but were of a general nature. Nevertheless, the non-generalized information is also presented here, including the following details:

(a) For the class of metallic materials, a necessary further standardization is suggested for "advanced" test methods such as:

(i) Fracture mechanics and testing of brittle materials;
(ii) Formability tests with sheet materials;
(iii) Crack initiation and propagation tests;
(iv) Random fatigue loading and life time assessment;

(b) For engineering ceramics, the development of methods for conventional strength properties (specimens and components) are of interest as bases for the standardization of long-time behaviour;

(c) For ceramics, testing during the total route of manufacturing, including powder processing, moulding the green compacts and the sintered components seems to be advantageous;

(d) Testing of the high-temperature corrosion resistance is another keyword for metallic and ceramic materials;

(e) Appropriate test methods are still needed for composites, especially for fibre reinforced polymers;

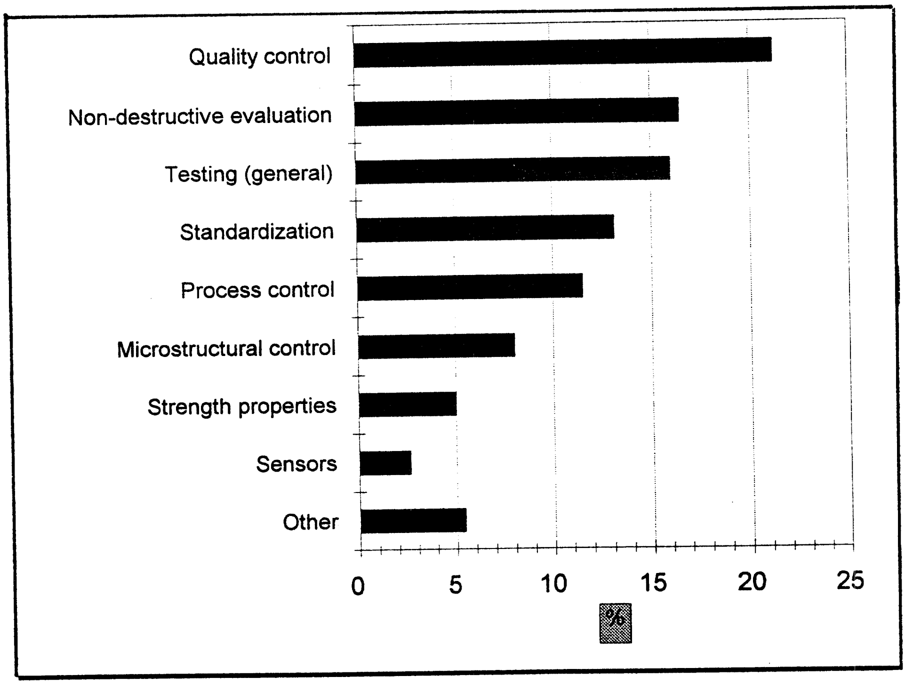


Figure 2.8. TESTING AND ASSESSMENT TECHNIQUES SUGGESTED FOR RESEARCH AND DEVELOPMENT
(200 entries = 100%)

(f) Some entries are related to an improvement of (low-cost) non-destructive testing (NDT) with respect to:

(i) Polymer matrix composites and polymers;
(ii) Engineering ceramics components before and after firing (on-line NDT).

(b) *General aspects of testing*

Focal points for R&D in the field of general testing and evaluation can be named as follows (again in an appropriate order of importance):

Paramount importance is attributed to all on-line quality control routes, manufacturing integrated control systems (process control) and computer-aided procedures. This includes:

- Laser based metrology and control
- Computer-aided image processing (surfaces)
- Development of sensors for various physical properties of materials and components

- Development of the automatization of the testing.

The application of all methods of non-destructive testing (NDT) is of special importance with respect to quality control; it contributes to other fields of more basic R&D such as:

- NDT for the evaluation of mechanical properties of materials

- Testing of bonding effects of composites and compound structures.

With respect to the strength of materials and components, the following keywords have been compiled:

- Testing under complex stress states

- Scale tests with respect to actual service conditions

- Short time tests and long service time performance evaluation of materials and components

- Early detection of damage; remaining service time

- Detection of deterioration by ageing

- Strength of gluings

- Analytical methods for an assessment of residual stresses.

With respect to other important properties or products, the following details were given by respondents to the questionnaire:

- Improvement of tribology tests, including standardization

- Tests for a characterization of pore structures; permeability for gas and liquids (e.g. for porous ceramics)

- Further development of acoustic emission testing methods

- Testing and modelling of anisotropic behaviour materials.

Special problems are arising with respect to the testing of microelectronic bondings and solderings, and in the field of civil engineering, where two further problems have been mentioned:

- *In situ* assessment of the performance of civil engineering structures

- Testing methods for fibre-reinforced, foamed and repair mixtures of concrete.

References

1.1 United States National Science Foundation. Materials Research Advisory Committee. Trends and opportunities in materials research. Washington, 1984.

1.2 Edmonds, D.V. New materials and developments in materials technology in *Enhancement of transfer of technology to developing countries*. Advisory Committee on Health Research (ACHR), World Health Organization (Geneva), 1987.

1.3 Ashby, M.F. and D.R.H. Jones. *Ingenieurwerkstoffe*. Springer-Verlag (Berlin), 1986.

1.4 Flemings, M.C. Structural materials: metals, ceramics, polymers and composites; pp. 31-42.

1.5 Cohen, M. Progress and prospects in metallurgical research, in *Advancing Materials Research* (Psaras, P.A. and Langford, H.D., Eds.). National Academy Press (Washington), 1987, pp. 51-110.

1.6 Van Griethuysen (Ed.). New application of materials; Forecasting and Assessment in Science and Technology (FAST) Report No. 203. Commission of the European Communities, Brussels, September 1987.

1.7 Birringer, R. and H.J. Gleiter. *Nanokristalline Materialien*; in *Neue Werkstoffe*, Band 1, VDI-Verlag (Düsseldorf), 1988, S. 95-108.

1.8 Flemings, M.C. Functional materials: electronics, information and sensors; in Ref. 1.4, pp. 43-48.

1.9 McG. Tegart, W.J. Civil engineering materials: cement, concrete and plaster, in Ref. 1.4, pp. 48-53.

1.10 Deppe, H.J. Renewable materials: wood and wood-based materials; in Ref. 1.4, pp. 53-55.

1.11 Chopplet, M. and J.P. Thiery. Biomedical materials, in Ref. 1.4, pp. 56-59.

1.12 Czichos, H., Helms, R. and J. Lexow. *Industrial and Materials Technologies: Research and Development Trends and Needs*. Bundesanstalt für Materialforschung und Prüfung, Forschungsbericht 181, Berlin, 1991.

Discussion of Part One, Paper One

Mr. Mohammad Kamel Mahmoud:

Q. Are there programmes in advanced materials in the EEC countries? What are these programmes?

Ans. The European Community has been working within a framework of several programmes. I cannot give the figures for the spending involved in these programmes, but I can say that the value of materials-related programmes amounts to ECU 550 million for four years, which is about DM 1,000 million, or $700 million.

The framework programme formulated specifies several other subprogrammes, such as basic research in industrial technologies, communications technologies, reference materials. There are, in addition, sectoral breakdowns according to various applications, such as metals or polymers for applications in aerospace or in other fields. There are also programmes on biology, environmental issues and cooperation within the framework of the technical topics.

Q. In Germany itself, is there a National Programme?

Ans. Yes, there is a National Programme which is called "Materials Research". Again, it covers the five major groups which I have mentioned: the metals, the polymers, the ceramics, the composites and the surface related areas as a auxiliary programme. There are the wear and friction problems.

Q. Who is funding these programmes?

Ans. The European projects are funded through the European Economic Community from the European Economic Community budget.

Ms. Wafa Abdel-Fattah:

Q. As you know, recycling is an international concern. In Egypt we are concerned with the ecological problems. Could you give us some examples?

Ans. Recycling and ceramics, or recycling in general?

Q. In ceramics in particular.

Ans. In ceramics, the problem is not that much of an issue. The quantities in advanced ceramics are comparatively low, and they do not constitute a hazard to the environment because, in general, they are thermally and chemically very inert. In other fields, there is concern about recycling in order to reduce the amount of dump-site volume, and to reduce the environmental impact from dangerous goods. For instance, food packaging of many types has bad effects on the environment. Therefore, the general issue is to reduce dumping by reducing the wrapping of various products. Incineration is not considered a good way of solving the problem immediately.

Another aspect is the polymers, which constitute a large percentage of the waste. They used to be dumped. There is an ongoing process to develop either the processes of taking the products back to the producer or having a thermal process for working on it, so that you need not select separately from the wide variety of polymers, but you choose just a general process, a heat process including water or hydrogen, and come back to a very valuable semi-processed co-product.

Mrs. A.O. Aribisala:

Q. In your presentation, there was a part on the use of aggregates, the use of renewable materials. As we know developing countries are busy developing their conventional materials, their traditional materials, like, kaolin and limestone. They are now going to change these to new advances in materials. They would be interested in integrating these materials into the new material as you mentioned in your paper. The way to start is to have a collaborative programme that enables us to enlighten such countries on what to do in processing the existing conventional materials as an input for new-material development. For example, if you take plastics, definitely there are some traditional materials that could be used as inputs in the new-materials industry. There should therefore be a way of integrating in order to avoid advanced and non-advanced development.

Ans. Advanced materials are basically characterized by a very low band of compositional or unintentional compositional variation. So if natural products fulfil this requirement, either by very selective mining or pre-processing to provide a comparatively clean product, it may be either natural or synthetic. Generally, however, in advanced materials, the natural materials have to be subjected to some additional processing in order to achieve the required purity.

Q. What is the role of the developing countries in achieving additional processing? What should be the action plan?

Ans. I do not have an answer. The answer lies outside the scope of the workshop.

Mr. John Wood:

Q. You mentioned that a number of advanced materials possessing very superior properties, such as amorphous metals, magnets, polymers, ceramics, etc. Now, hardly any of these, even after an intensive R&D, have reached the profitable state. For instance, there is the amorphous metal programme in the United States, where the production part is working at only 10% capacity. I started working in 1971 in this area, a long time ago; I wonder if the property advantages are actually very important in determining materials strategy and investment?

Ans. I have not worked in this field myself.

Paper Two

THE IMPLICATIONS OF NEW AND ADVANCED MATERIALS TECHNOLOGIES FOR THE DEVELOPMENT OF THE ESCWA COUNTRIES

Lakis Kaounides

I. DEFINITION OF MATERIALS SCIENCE AND ENGINEERING (MSE)

The word "materials" refers to a wide category of products such as superconductors, metals, polymers, composites, semiconductors, or biomaterials. A recent study of the subject[1,2] has shown that there are four basic elements in the field of materials science:

(a) Properties or phenomena that make a material interesting or useful;

(b) Performance: the measure of usefulness of the material in actual conditions of application;

(c) Structure and composition: this includes the arrangement and types of atoms and molecules that determine properties and performance;

(d) Synthesis and processing: this includes the methods utilized to achieve the desired arrangements of atoms and molecules.

The science and technology of materials consists of the application of these four fields to each material: the properties may have to do with the strength or optical behaviour; performance depends on the variation of these properties under specific conditions of temperature, pressure or a particular chemical environment; the structure and composition is what brings about the properties in question; the synthesis and processing constitutes the operational methods that result in the desired material.

In other words, the mastery of the four fields is essential to produce each material. Materials Science and Engineering (MSE) is the name given to this complex of specializations. MSE, which is of an interdisciplinary nature, provides the unified, integrated approach cutting across all classes of materials.

Intensive development of new materials has been taking place over the past 30 years; but the processes have been mostly in the R&D phase and in hi-tech industries. The limited R&D level of work in the third world and the absence of hi-tech industries has kept these momentous developments hidden from the view of third-world bureaucratic planners.

The papers presented at the Workshop on the Implications of New and Advanced Materials Technology stress the following features of advanced materials which must be kept in mind to facilitate formulation of useful policies:

(a) Innovations are taking place at a high rate; as a result, the product cycle is short. Thus, the total time available to select a particular material, manufacture the product, market it and recover the total cost of development and investment is a matter of a few years.

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[1] Materials Science and Engineering in the 1990s: Maintaining Competitiveness in the Age of Materials, Committee on Materials Science and Engineering, National Academy Press (Washington, D.C., 1989).

[2] The complete list of references appears on page 248 *ff.*

This high rate of technical change poses very serious difficulties to ESCWA and other third-world firms where the speed of planning and implementation is slow;

(b) New materials are directly integrated into the process of manufacturing new products; thus it is not useful to view the production of new materials in isolation of manufacturing industries. Consequently, in order for ESCWA member countries to participate effectively in MSE activities, they must exercise considerable analytical efforts to determine viable strategies for their participation in a mature and complex industry. It is essential for the ESCWA member countries to acquire the capacity to plan and evaluate strategies for managing their participation into what is already a complex and international industry;

(c) The adoption of high standards and effective quality-control methods is an integral part of the process of designing and producing new materials. International competition has forced all new entrants to adopt high standards because consumers expect high quality products at low prices;

(d) There is no sharp dividing line between "old" and "new" materials; old and new materials are interdependent. Manufacturers in the ESCWA member countries have generally neglected to establish scientific and technological R&D support systems for the production of traditional materials; the capacity of existing manufacturers to respond promptly to international challenges has thus been weakened.

II. THE REVOLUTION IN MATERIALS SCIENCE AND ENGINEERING IN THE 1980s: CHARACTERISTICS AND CONSEQUENCES

A. THE MATERIALS REVOLUTION

1. *Origins*

The insights offered by quantum physics in the early part of this century greatly enhanced understanding of the interconnections between the structure and properties of matter. In subsequent decades, the analysis, synthesis and processing of materials has benefited from the incorporation of more fundamental scientific understanding, leading to advanced materials in atomic energy production, electronics, and space programmes, among others. Nevertheless, such enhanced theoretical insights could only offer qualitative guidelines to modelling and prediction.

It was only very recently that quantum insights could be more fully utilized. Since the beginning of the 1980s, a proliferation of powerful new instruments (see figure 2), such as the tunnelling scanning electron microscope, has provided scientists with in-depth insights into the electronic, atomic and molecular structures of materials. Moreover, the exponential increase in computer power, through the use of high-speed supercomputers, has enabled scientists to develop mathematical models of very complex physical phenomena which defied calculation even a few years ago. There has therefore been a quantum leap in understanding the processing-microstructure-performance relations and the physical, chemical and mechanical behaviour of both monolithic and composite materials. Using advanced computer-aided instrumentation, mathematical modelling and experimental techniques, materials scientists are now beginning to offer quantitative characterization of microstructures, thus describing the structure of a material as it evolves during processing, and its relation to the resulting properties.

2. *Characteristics*

Modern MSE has emerged from its diverse scientific roots in condensed-matter physics, solid-state chemistry and synthetic chemistry, combined with practical engineering and manufacturing experience and industrial R&D laboratory research to offer a comprehensive approach to materials.[3] At centre stage is the close interaction and close relationship between the structure/composition, properties performance in use, and the synthesis/processing path of a material (figure 2). This approach is now both necessary and applicable in all classes of materials, thus rendering all other empirical and craft-related approaches to materials development obsolete. Improvements in existing materials and the introduction of new materials are thus predicated on the methods and tools of a modern MSE in possession of a strong component in basic science coupled with a comprehensive processing, fabrication and engineering base. Given the permeation of modern MSE in all classes of materials, there is a sense that which all materials are becoming "new" materials. By the late 1980s, materials science and applied research had achieved greatly enhanced capabilities for manipulating and building materials which had been inconceivable even at the beginning of the decade. For example, at the atomic level:

> "... instruments such as the scanning tunnelling microscope and the atomic resolution transmission electron microscope can reveal, with atom-by-atom resolution, the structures of materials. Ion beam, molecular beam, and other types of equipment can build structures atom layer by atom layer. Instruments can monitor processes in materials on time scales so short that the various stages in atomic rearrangements and chemical reactions can be distinguished. Computers are becoming powerful enough to allow predictions of structures of time-dependent processes, starting with nothing more than the atomic numbers of the constituents.
>
> "At higher levels of structure, researchers are beginning to understand and build, structures with crystals or "grains" that contain only small groupings of atoms, in which as many atoms lie in the grain boundaries as in the grains themselves. Researchers are also finding new properties in "nano-composites"--composites on the scale of nanometres. Element sizes in electronic chips are rapidly decreasing and are approaching the size of small groups of atoms.
>
> "Moreover,... the level of microstructure above the nanometre scale continues to have rich promise for research. Developments at this level include modern composites, directionally solidified high-temperature turbine blades and

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[3] United States National Research Council, Materials Science and Engineering for the 1990s, National Academy Press, Washington, D.C., 1989.

flaw-tolerant ceramics. Development and application of modern fracture mechanics have also been important. Much of the innovation and development in modern processing is concerned with controlling structure at this level as well as at finer levels. Examples include new strip casting processes and near-net-shape forming. Major opportunities exist for computer modelling to aid development of new processes and more rapid introduction of new designs and novel production processes."[4]

At the core of the materials revolution is this ability of materials scientists to intervene at the electronic, atomic, molecular and macrostructural levels, to quantitatively characterize, model, predict and control the structural evolution along the processing path, and to manipulate and enhance properties in order to achieve desired industrial and military applications. It is also responsible for the great improvements in the properties and processing technologies of traditional materials and the proliferation of knowledge-intensive, high-performance materials such as advanced ceramics, engineering polymers, advanced metals and composite systems consisting of ceramic, metal or polymer matrices[5] (figure 6). Although the 1960s and 1970s did witness the introduction of important new materials which could be viewed as advanced materials, the developments of the 1980s marked a structural break in the mode of development and utilization of materials in industrial systems. The MSE and its exponential ability to understand the forms and behaviour of matter, predict and create new forms and control its uses are leading to massive transformations in both materials-producing and using firms and industries. The imperatives in the expanding pure and applied materials scientific frontier, as well as its consequences for strategic responses and reorganization of firms and industries internally, domestically and globally, are examined below.

3. *The multidisciplinary nature of modern MSE*

The need to examine the manifold aspects of materials structure, composition, phenomena, characterization, synthesis, processing and fabrication techniques involves the integration and interaction of many hitherto specialized fields and disciplines, increasingly pooled in synergistic collaboration. Materials science is now a multidisciplinary science requiring inputs from solid-state physics, chemistry, metallurgy, ceramics, composites, surface and interface sciences, mathematics, computer science, metrology and engineering. In fact, rigid separation of the different disciplines is becoming inappropriate and barriers or boundaries between them are beginning to erode. The trend in modern science towards an examination of elementary particles, atoms, and molecules encompasses all materials, whatever their origin, and indeed crosses over and embraces other fields, such as biotechnologies and genetic engineering of living organisms. Indeed, recent evidence points to a merging of life sciences (molecular biology) and chemical science and polymeric materials. New developments have facilitated the micro-electronics revolution. In turn, developments in microelectronics have repeatedly given added impetus to chemistry via, for example, computer-aided molecular design and a more efficient search for new active substances, or microprocessor control of manufacturing

[4] Ibid., pp. 74-75.

[5] The classification of new materials, on the basis of their qualities and function, by the Industrial Bank of Japan is shown in figure 5.

processes. New discoveries in physics and biology greatly expand the fields open to chemistry. Hence, breadth of knowledge and synergistic collaboration are now fundamental to the conduct of basic research. In any case, the nature and complexity of the problems in materials synthesis and processing is such that a joint simultaneous team effort in many disciplines is now clearly required. Multidisciplinary materials design, product development and processing capabilities are therefore becoming crucial in the firm, the industry, the university, the research laboratory and even the economy.

4. *The importance of synthesis and processing*

Materials research and development now require that materials scientists become closely involved in the processing and fabrication stages of production. The microstructure of materials, i.e. the arrangement of atoms into crystalline arrays or disordered structures, determines properties and performance, but the mechanism that links all of them is processing. The controlled processing path which a material follows will affect its microstructure and therefore its properties and performance in use. In the past, processing techniques were largely non-scientific and empirically based. However, the scientific content of the material as well as the materials processing technology in both traditional and new advanced materials has now increased significantly.

(a) Science into processing

Thus, materials scientists of all disciplines and specializations are becoming increasingly involved in the processing and fabrication stages of materials development. Conversely, materials engineers need to be closely attuned to the scientific and theoretical aspects of materials design and modelling. This has produced close integration of the subject matter of materials science and engineering as regards its pure and applied aspects, which are necessarily viewed as a coherent whole. At the same time, this has led to fruitful feedback and cross-fertilization between scientific understanding and the engineering problem of processing materials, such as controlling structure and improving performance, reliability and reproducibility at low cost. The infusion of science into processing has led to several new processing technologies, without which new materials would have remained curiosities and existing materials would not have registered the tremendous improvements in properties, performance and cost that they have displayed of late. Such new processing technologies (see figure 3) are being developed through the use of computer controls, sensors, process modelling, artificial intelligence, in-process non-destructive testing, etc.

Improving the properties of existing materials or creating entirely new materials is virtually useless without the development of the necessary processing technologies as well as the equipment and machinery to manufacture the components, shapes and subassemblies of complex engineering systems and final assembly. Processing is a major constraint in the commercialization and practical application of high-temperature superconductors, photonic and opto-electronic materials, biochips and many materials engineered at the molecular level. In metallic materials, the insights of MSE have been utilized to offer dramatic improvements in properties, performance and processing costs in a new generation of high-performance metals and metal-matrix composites as compared to commodity metals a decade ago. New processing methods,[6] such as rapid solidification processing, hot-and-cold isostatic pressing, electron beam processing, superplastic forming, metal injection moulding and many others are leading to great improvements in the performance of metals. At the same time, intermetallic alloys, magnetic alloys, electronic alloys, new superalloys, high-strength steels, light-metal alloys (e.g. aluminium-lithium) and metal-matrix composites and laminated systems, are offering dramatic improvements in performance, costs and manufacturability; thus, they fend off competition from ceramics and polymers while opening up new uses for metals.

(b) Synthesis

Synthesis underlies the discovery of new materials exhibiting new phenomena (e.g. the high-temperature superconductors in 1987), the improvements in the control of the structure, composition and hence properties of known materials as well as the progress in the development of materials processing and manufacturing technologies. Synthetic capabilities of the chemical and physical combination of atoms and molecules to form materials and their coupling to characterization and analysis of properties, processing and manufacture are emerging as crucial determinants of progress in pure materials research, the rapidity of translating basic research to commercial applications and the rate of technological change in various industrial sectors. Although the synthesis element of MSE necessarily retains a large scientific base, it is nevertheless organically connected to the processing and manufacture of solid materials. The choice of synthetic reactions influences subsequent processing paths, as in the preparation of high-purity powders for advanced ceramics fabrication. Also, modern fabrication technologies involve the merging of the synthesis and processing stage into a simultaneous process, as in injection moulding of plastics. Thus, materials synthesis, processing, fabrication and manufacturing are merging in response to forces internal to MSE as well as pressures emanating from the evolution of new production technologies. Another factor is the ever-increasing need to transmit fast and efficiently, materials pure research into industrial and military applications.

At present, a major constraint in the diffusion of advanced materials into a wide range of technologies and industrial applications is the inability to process raw or synthesized substances into reliable, useful low-cost forms in high volume, such as film, wire, components, devices and structures entering complex engineering systems. This is most evident in advanced structural ceramics, composites and the new high-temperature superconductors. Moreover, it is becoming clear that technological competence in materials processing and fabrication is the critical component in the international competitiveness of national industries engaged in traditional and high-technology activities. Such processing capabilities facilitate more rapid translation of research results into commercial applications as well as the generation of higher-quality, more reliable, low-cost products of innovative design in a wide range of increasingly sophisticated manufacturing industries. This is evident from the experiences of Japan and, to a lesser extent, the Republic of Korea, where manufacturing capabilities and associated materials processing technology have been developed concurrently to great advantage in terms of innovation and global competition.

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[6] United States Bureau of Mines, *The New Materials Society*, vol. II, 1990, chapters 4 and 5.

Figure 1. Materials, high technology and manufacturing in the 1990s

QUANTUM THEORY
1930s-1970s
Slowly permeates and eventually rejuvenates metallurgy, chemical/ electrical/electronic industries. Science base of metallurgical practices, and chemicals enhanced. Rise of MSE 1960s-1980s.
In 1980s
Quantum insights taken full advantage of: Theoretical understanding, modelling, quantitative prediction.
Use of Supercomputers. Ability to synthesise, process and tailor materials to specific applications.

A: 17th Century, 1st Revolution in Physics - Application of Scientific Method to Study of Matter, Force and Motion.

B: 1890s-1920s, 2nd Revolution in Physics - Radioactivity, Relativity, Quantum Theory. An explosion of new ideas. Much of modern science and technology based on it. Much greater understanding of Matter; Forms, Behaviour, Transformations. Increasingly possible to predict behaviour, create new forms, control its form and uses. Gradually permeates all physical sciences - enhances science base of existing technologies and leads to scientific breakthroughs and major new industrial technologies 1930s-1980s: Atomic power, Lasers, transistors, IC, micro processors, TVs, radio, and power, functionality of computers vastly increased.

C: 1980s-1990s, 3rd Revolution in Physics:
THE NEW PHYSICS: Major new conceptual and practical advances across a broad front. (Beyond mere application of quantum theory).

→ **Revolution in Materials Science and Engineering Mastery over Matter** ← Both embedded in quantum leap in scientific understanding. → **High-Technology, Science Driven/Based Industries**
↓
Aerospace, Defence, Microelectronics, Telecommunications, Biotechnologies

MATERIALS NEEDS

1. Progress in ALL major new technologies in materials constrained.
2. Stringens specifications and extremely demanding performance characteristics in high-tech and manufacturing.
3. Integration of materials design and processing with end-product design, manufacturing and assembly steps. Eg Aircraft, Automobiles - sub assemblies and components.

↔ Diffusion of IT across manufacturing: Information related innovation. Highly stringent performance requirements in new manufacturing production processes. Instruments, sensor, and measurement technologies rise in complexity.

MATERIALS CAPABILITIES

1. Proliferation of new and improved materials. Accelerated materials invention and innovation.
   → Science, technology driven. Demand driven. Facilitates flexibility, variety, choice in manufacturing product and process design.
2. Tailorability/Customisation. Meeting high performance, extreme environment (requirements in user industries. Close attention to user needs.
   → Market, user driven. Enables technical change and growth in high-tech/defense industries and broad range of manufacturing industries.
3. Entirely new materials can be synthesised and processed: Superconductors.
   → Unforeseen and entirely new products and industries. Revolutionising existing infrastructure and related technologies.

Figure 2. New analytical technologies

The development of advanced high-resolution analytical technologies has provided materials scientists with a repertoire of tools with which to probe the intrinsic electronic structure of all materials.

This has led ultimately to an improved understanding of the fundamental nature of the "solid state".

High-voltage electron microscopy
Scanning electron microscopy
X-ray diffraction
Excitation spectroscopy

Electronic level
↓
Atomic level
↓
Molecular level
↓
Grains
↓
Macroscopic level

Figure 3. New materials processing technologies

New Processing technologies enable scientists to alter the structure and, ultimately, the performance of materials.

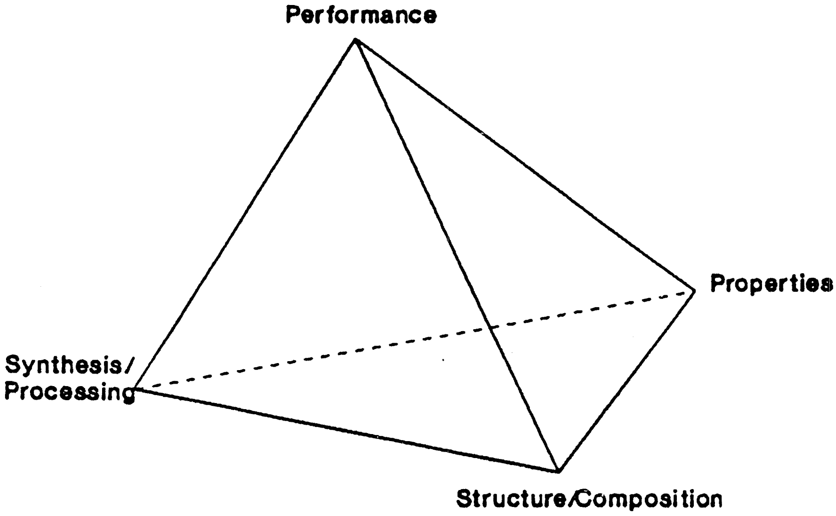
Such advances have enabled material scientists to improve existing materials as well as to create new manmade engineered materials" with properties tailored to meet the special needs of the end user.

Rapid solidification
Vapour phase deposition
Ion implanation
Molecular beam epilaxy

Structure
↓
Properties
↓
Performance

Source: L. Sousa, “Problems and Opportunities in Metal and Materials”, U.S. Bureau of Mines, 1988.

Figure 4. The four elements of materials science and engineering



Source: L.C. Kaounides, 1992; Materials Science and Engineering for the 1990s, National Research Council Committee on Materials Science and Engineering, 1989, p. 29.

5. *The integration of scientific, engineering, manufacturing and marketing capabilities*

In addition to the vast enhancements in the scientific and knowledge contents as well as the interdisciplinary efforts required in materials development and production (and use) in the 1990s, serious implications exist.

(a) Simultaneous materials, manufacturing and product design

Divisions between engineering and materials science have now been eradicated, resulting in interaction and integration. Moreover, it is becoming necessary to combine materials science with manufacturing, product design and performance into a simultaneous process, in contrast to the sequential and disconnected product and process development path hitherto followed in materials industries. For example, in metals, the product development process followed the sequence of new alloy creation by the alloy technologist, who then handed it to the ingot caster, who then passed it to the fabricating technologist and then, finally, it reached the product designer after an average wait of seven years! This serial and lengthy one-way process of material development and production is out of date in today's market-place and competitive environment, which requires the creation, testing and application of complex new materials technologies in record time. It is not simply a question of speeding up the R&D and innovation cycle. Rather, the new conditions in materials science necessitate a simultaneous, two-way approach (see figure 7) to materials research, advanced manufacturing techniques, product design, performance and marketing, including close interaction and integration with end users which is crucial. The scientific and engineering capabilities of the materials producers need to be in close touch with the performance requirements and engineering and manufacturing processes employed by the end-user industry, e.g. automobile or aerospace. Although development of new materials has to a large extent been driven by demand, generalized application requires that end-users be educated as to the properties, quality and reliability of a new material.

(b) The integration of materials producer and end-user design and manufacturing procedures

In short, what is emerging is not only a breakdown of a firm's traditional internal divisions and sequential procedures in research, development, engineering, manufacturing and marketing, but also an enforced integration of product design into the manufacturing technology and product design of the end-user. This explains the forward integration of materials producers and backward integration of materials users. These observations acquire added significance when viewed in conjunction with the increasing application of flexible, micro-electronics-based automation technologies in manufacturing and the trend towards a systematic integration of all aspects of the production process into computer-integrated manufacturing.

6. *New approach to costs: total system costs*

New materials, which are generally more expensive than existing materials, especially metals, necessitate a different approach to costs by end users. To take advantage of the properties and performance characteristics of a new material, end-users need to redesign both product and manufacturing techniques. Hence, a system-wide total approach to costing must be taken, where potential savings in tooling, assembly, fabrication, maintenance and life cycle costs could offset the higher cost of advanced materials. It is no accident that many current applications of advanced materials are in areas, such as the military or the aerospace industry, where performance is presently more important than cost.

7. *The long-run importance of "materials systems"*

An important view in industry is that the performance requirements for materials for current and future use necessitate the development of combinations of materials or engineered "materials systems" for which microstructure is designed to maximize the properties of the constituent parts as well as those of the whole. Stringent specifications for extremely demanding performance criteria from end-user product designers require overcoming the limits on engineering flexibility and performance optimization imposed by today's monolithic materials. Engineered materials systems can combine materials from the same or different families as shown in figure 6. Such complex needs further strengthen the integration of materials science, product design, manufacture and a planned, cohesive marketing capability in close contact with materials and end-users. Furthermore, it signals the transformation of existing monolithic-materials producers into large and integrated materials producers. It is those companies that combine the necessary scientific and engineering expertise with the appropriate marketing, sales and collaborative strategies with end-users that will become dominant in the next two decades.

Advanced materials-systems, with their vast scientific and engineering requirements as well as testing, instrumentation and research expenditures, are proving to be beyond the means of individual companies. Already this has led to large collaborative efforts and consortia among industrial companies, universities and Governments. This will increasingly become one of the major features of the materials revolution.

8. *Summary of materials science and engineering 1960s-1990s*

Materials science and engineering has, since the 1960s, been predicated upon an unbreakable link between science and engineering technology as well as a necessary integration of several scientific and technological fields (e.g., physics, crystallography, inorganic chemistry, metallurgists, ceramicists, electrical and chemical engineering).

The aim and underlying philosophy of this organic, multidisciplinary link is to provide scientific and technological solutions to the design and production of new materials engineered for specific uses. To do this, MSE uses scientific understanding (which derives from theory, advanced instruments, experimental techniques and experience) to (a) delve into the microstructure and composition of materials; (b) connect the insights obtained from this to the materials' properties and performance; and (c) use this information to process and shape the designed materials in a controlled manner so as to produce materials with the required properties and performance. Thus, MSE translates fundamental understanding of atomic and molecular microstructure into the performance of materials and end products.

Throughout its relatively short existence, MSE has, in fact, engendered great flexibility in the manufacturing process and in business strategy. An example of this is its capacity to resolve bottlenecks and constraints in particular applications by offering a great many options to materials users as well as ever-improving quality inputs for new and improved product designs. This is especially useful when the industrial system is undergoing an internal transformation emphasizing flexibility in production and market response.

In this, MSE brings with it from its very inception the concept of 'purposive creativity',[7] i.e., the directed, purposive use of expanding scientific and technological knowledge to meet specific material needs or to create entirely new, theoretical materials.

Within the realm of its close concern with and connection to customer and market needs, MSE has the important intrinsic ability to both respond to end-use technology or market forces and to freely create new materials use exists but which can lead to entirely new designs, products and activities.

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[7] A term coined by Melvin Kransberg and Cyril Stanley Smith, "Materials in History and Society", in *The Materials Revolution*, Tom Forestor (ed), Basil Blackwell, 1988.

Figure 5. Classification of new materials on the basis of their qualities and functions

Category	Material	Function	Utility (property): material sample
New Materials – Inorganic materials	Metals	Electric function	Solar cell (light-electricity convertibility): amorphous Sr. High speed operation L.SR (high electron mobility): (iaAs; linear-motor cars (superconductivity); NiTi alloy, ViCa alloy.
		Magnetic function	Magnetic memory materials (ferrumagnetism): impalpable powder alloy; SrCo alloy; transformer iron core, magnetic head (high magnetic permeability): amorphous alloy.
		Mechanical function	Pipe couplings (shape-memorey characteristic); NiTi alloys, CuZn alloys; precision machinery component materials (vibration-free characteristic): Mg alloy; nuclear power station equipment and aircraft components (high strength): NiCoMo alloy.
		Thermal function	Gas turbines, heat pipes (heat resistance): Nickel alloys, cobalt alloys.
		Abserption function	Hydrogen engine cars (hydrogen storage characteristic): FeTi alloys, MgNi alloys.
	Nonmetals	Electric function	IC packages (insulation): Al2O1: resistance heaters (electric conductivity): ZrO2; ignition element (piezoelectricity): ZnO; capacitors (dielectric character): BaTiO3; varistor, gas sensors (semiconductivity); SnO2, BaTiO3, thermal sensors (ion electric conductivity): PSZ; electrode material for electron guns (radiation): TiC.
		Magnetic function	Ferrite magnets, magnetic tape (magnetism): BaO2Fe2O3, SrO2Fe2O3.
		Mechanical function	Cutting tools (machinability): TiC, TiN; bearings, boring drills (abrasion resistance): Al2O3, B2C, precision wheel teeth (strength in high temperature): Si3N4, SiC.
		Thermal function	Turbine blades, engines (heat resistance): Al2O3, SiC, Si3N4; adiabetors for nuclear reactors (adiabetion): K2OTiO2, Al2O3, heat radiation panels (heat transfer): BeO.
		Optical function	Laser diobeds (fluorescence): CaA2; YAG; Sodium lamps (transparency): Al2O3, AJON, MgO; optical fibers (transparency): SiO2.
		Biological functions	Artificial bone, artificial teeth (histocompatibility): AL2O2, CA2O(PO4)2(OH2).
		Absorption function	Bioreactors (enzyme-fixing character): porous glass; catalyst carriers (absorption): porous silica, AL2O3.
New Materials – Organic materials	Polymeric materials	Electric function	Printed circuit boards, dielectric for capacitors (insulation): polyimide; electrodes (electric conductivity): doped polyacetylene.
		Mechanical function	Structural materials (high strength): aramid fiber; speaker cone material (high elasticity): high molecular whisker.
		Thermal function	Heat resistance structural material (heat resistance): polyamid, polyimide; cold resistance rubber (cold resistance): fluoro-rubber.
		Optical function	Optical fibers (transparency): PMMA; resist, photoprint material (photoreaction): photo-hardening resins.
		Biological function	Artificial blood vessels, artificial hearts (biological compatibility: silicone, fluorine-contained resins; artificial soft tissue (histocompatibility): silicone resins; artificial kidneys (biological compatibility): acrylic resins, methacrylic resins.
		Separation function	Gas separating membranes, reverse osmotic membranes (separation character): cellulose discetate.
		Catalyst function	Polymer catalysts: very strong acid resins.
New Materials – Composite materials	Polymeric composite materials	Mechanical function	Spacecraft, aircraft, automobiles, ships, game and sports equipments (high strength and lightness): * Basic material - epoxy resin, unsaturated polyester, polymide. * Reinforcement - carbon fiber, ceramic fibers, boron fibers, aramid fibers.
	Metal composite materials	Thermal function	Equipment related to nuclear power generation, gas turbines, space and aircraft (high strength and heat resistance): * Basic material - aluminum, copper, titan, nicket. * Reinforcement - ceramic fibers, boron fibers, whisker.
	Ceramics composite materials	Thermal function	Gas turbines, internal combass: engines, rockets, equipment related to nuclear power generation (high strength and heat resistance): * Basic material - alumina, silicon carbide, silicon dioxide. * Reinforcement - ceramic fibers, metal fibers, whisker.

Source: Industrial Bank of Japan.

Figure 6. Advanced material systems

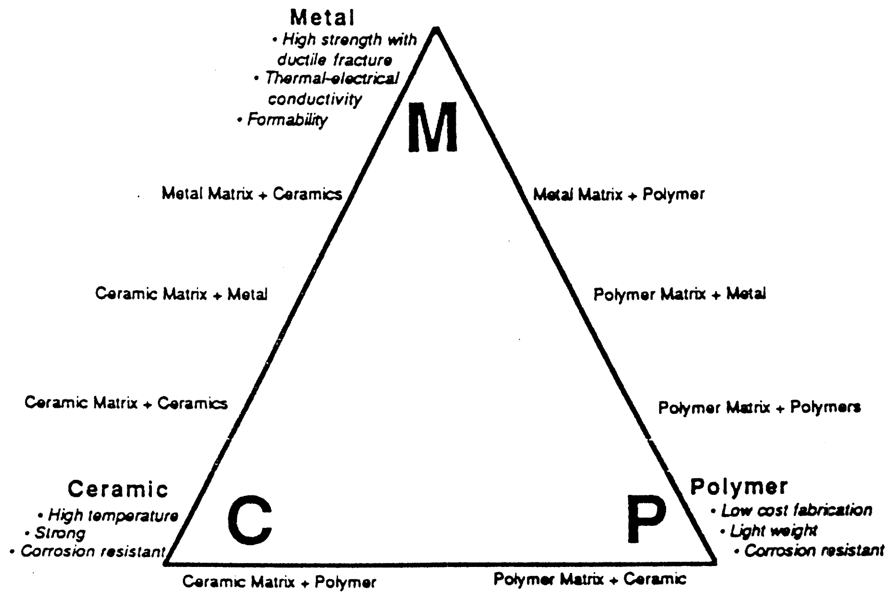
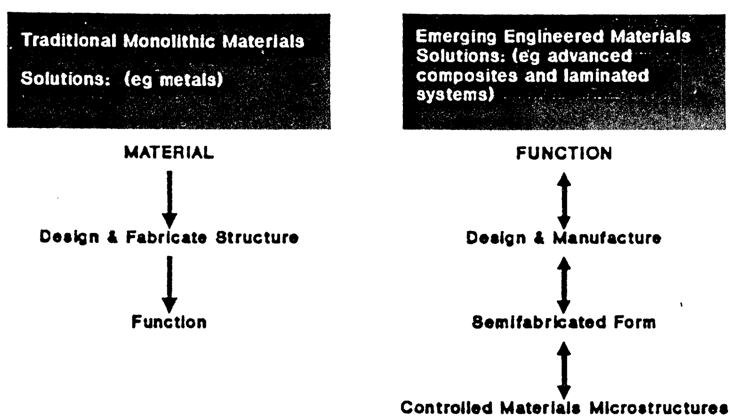


Figure 7. Integrating materials, manufacturing and product design



Sources: Alcoa, position paper from the 10th Biennial Conference on National Materials Policy.

The above-mentioned developments have begun to exercise considerable influence on the restructuring and reorientation of traditional materials-producing branches of industry. In fact, economies are moving away from the metals base of the post-Industrial Revolution era to a comprehensive materials-producing and -using base. Below is a brief summary of the major consequences of the materials revolution for industrialized economies.

B. THE TRANSITION FROM METALS-BASED TO NEW MATERIALS-BASED ECONOMIES

1. *The restructuring of primary input producing branches of industry*

Primary and processing branches situated at the earliest stages in the structure of any production (stages 1, 2 and 3 in figure 8) engaged in the extraction, primary processing and semi-fabrication of inorganic and organic minerals and natural fibres are in the midst of a fundamental restructuring. This, however, goes far beyond the cost-cutting, defensive responses and rationalization measures that have been aggressively adopted in recent years,[8] enabling producers to survive the prolonged adverse market conditions which mining and commodity-metal and chemical industries experienced in the 1980s. Concurrent with the reorganization, the modernization of remaining plants, and the redeployment of large segments of bulk metal and chemical branches abroad, developed market economies are steadily experiencing a transition towards the production and use of high-value-added specialties and, importantly, advanced materials. Thus, while domestic extractive and primary processing branches are declining due to high costs and market pressures, including cheaper, imported bulk commodities, there is an increasing emphasis on further downstream processing and semi-fabrication of high-value-added differentiated products.

Nevertheless, this shift towards vertical integration, diversification, product differentiation and high-quality, high-value-added market niching is occurring in the context of the revolution in MSE and the consequent permeation of the early stages of production with vastly improved scientific and technological capabilities. This is leading to radical new technologies at the extractive end and primary processing of bulk materials. It is also enabling the development of high-quality, semi-fabricated mill products and specialties for specific uses. At the same time, the shift towards high-quality downstream production of traditional materials is accompanied by, and is indeed becoming integrated with, the emergence of advanced materials such as engineering polymers and advanced ceramics and composites. In many cases it is firms in traditional metals, chemicals, glass and ceramics that are diversifying, becoming capable of producing multi-materials and high-technology advanced materials.

The transition of advanced market economies from the era of primarily metal production and application to that of multimaterial and, more specifically, "new materials producing and using economies" is far-reaching indeed. The arrival and progressive diffusion of advanced materials capabilities entails sharp discontinuities with past methods of production, structure of basic industries, and mode of utilization of materials in the economy. Until relatively recently, i.e. the 1960s, materials in the economy were essentially synonymous with

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[8] For empirical evidence, see "The Restructuring of Industry 1970s-1990s", by L. Kaounides, a paper presented at the fourth EADI Conference, Oslo, June 1990, upon which this section is based.

"metallurgy". University graduates emerged with degrees in metal science and metallurgy, knowing very little about ceramics, polymers, or composite materials. Over time, however, the production of high-performance engineering polymers, composites and advanced ceramics has gained increasing importance in parallel with the transformation of the materials science and engineering content of academic and industrial research departments. These movements are schematically shown in figure 9.

The relatively clear delineation within metals and between metals and competing materials, such as plastics, in the post-war period, and the determining influence that these materials impose on the type, quantity and properties of the final products of an economic system, have fundamentally changed. Despite the subsequent manipulation of the original material, the basic properties of the latter still reign supreme in their incorporation in the final product. Not only can the properties of the original materials be radically altered and new materials synthesized to the desired combination of properties, but also the barriers in materials and their designated markets have been lifted. In a multimaterial-producing economy, any material can easily penetrate the market of any other. That is, an end-use specification can be met by a variety of materials, or, viewed differently, by a material of any origin. Thus, one company can produce different materials which compete for the same application. This happens because the scientific capabilities exist, but it is also part of a rational marketing strategy which enables the company to reap commercial benefits from replacing existing materials with new ones that possess superior qualities, as well as pre-empting competition. The scientific and engineering capabilities which the materials sector possesses, together with the interpretation of materials end-users, are ushering in new imperatives for corporate research, production and marketing strategies, which are not as yet understood, partly due to the fact that these are only beginning to take concrete and definable forms. Moreover, the transformations under way are introducing large-scale structural changes in traditional basic industries and altering their relative importance within national industrial structures as well as globally over the long run. Also, the new multimaterial- producing industries crucial to the production of durable consumer and industrial goods can impart new flexibility and dynamism to the progress of production and consumption in the economic system.

The new materials technologies and differentiated, high value-added production patterns are in consonance with the requirements and market conditions that have emerged and acquired prominence in IACs (industrialized advanced countries) during the last two decades.

The materials sector as a whole is becoming integrally linked to the design and manufacturing process of user industries due to new technological and market imperatives acting on both. The intervention of a multimaterials sector in the heart of the manufacturing industry imparts thereby new possibilities and flexibilities to the manner of operation of the latter; but it also ushers in constraints and difficulties of a managerial and skill-related nature. The foregoing should not be interpreted as implying one-way, materials-supply-driven progress and growth. Rather, account should be taken of the fact that the needs and trends of user industries, indeed, of consumption, are the primary factors which will lead to changes in the materials-producing-system. In other words, to understand any future change in basic industries, innovation trends in materials using industries should be examined closely, as these industries, in turn, impose requirements upon and drive new materials development, as in electronics.

2. *Emerging tendencies of the materials subsystem*

This section examines those structural changes occurring in the early stages of the production structure of industrial systems, which for simplicity's sake have been assigned to stages 1,2,3. Figure 10 concentrates on Sector I and offers a very simplified, shorthand view of the emerging materials subsystem. Economies are beginning to shift from a metals base to a materials base or, increasingly, one of advanced materials. Commodity metals, although increasing in purity, enter into advanced alloys, components and matrix composites utilizing more advanced fabricating technologies. They also compete with advanced ceramics and polymers and their fibre-reinforced matrix composites for high-technology and other high-performance applications that are increasingly being demanded throughout the manufacturing industry. A number of points emerge from this excursion into the materials aspect of the restructuring process from the 1970s to the 1990s, some of which can only be preliminary and speculative.

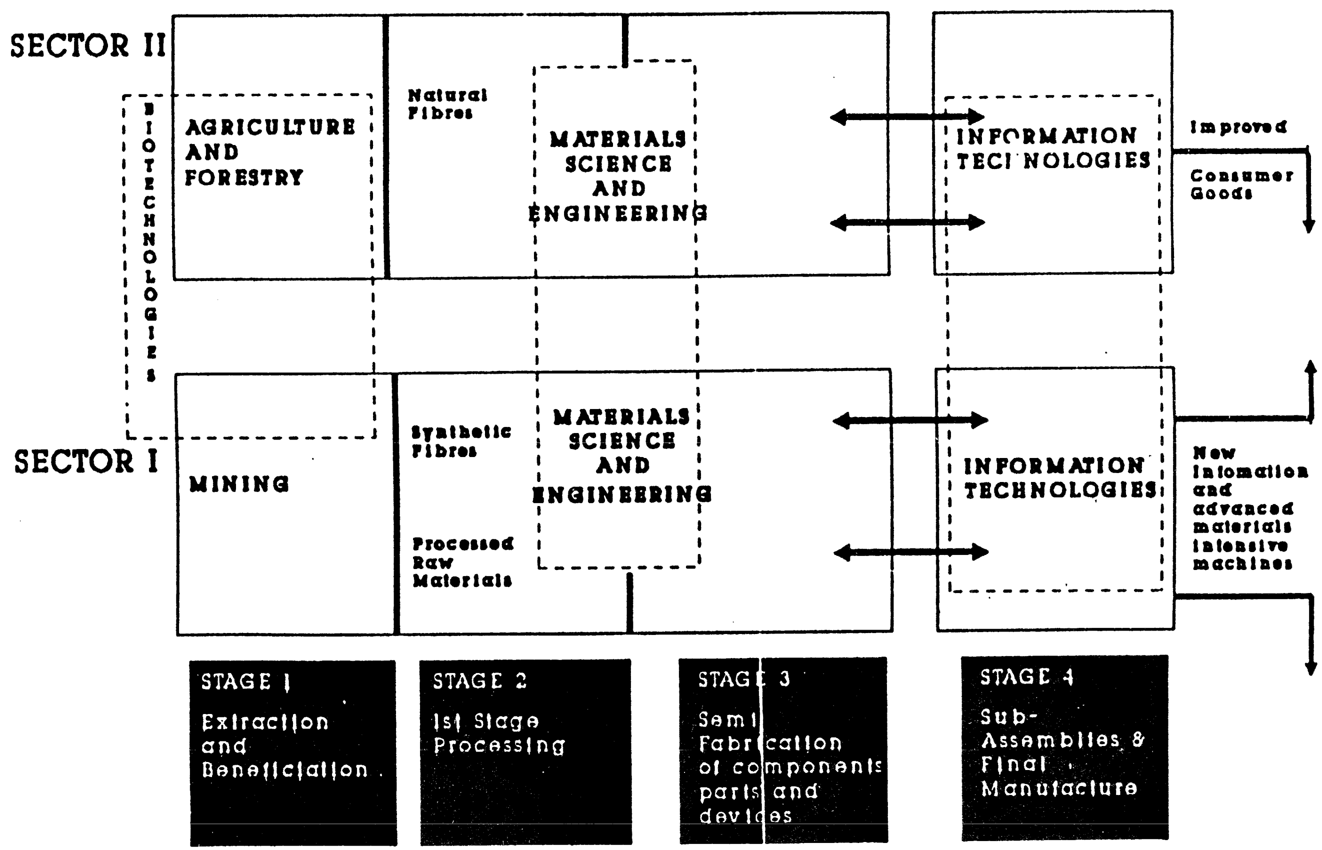
(a) Restructuring and redeployment of commodity metals and chemicals

The restructuring of the mining, base-metal and petrochemical sectors in the 1970s and 1980s has led to a smaller but technologically superior presence of such branches within IACs. At the same time, there has been an expansion of the degree of processing undertaken by developing economies, and the rise of commodity-metal and petrochemical production in developing economies is a major new variable in the global market for these materials, intensifying competition and the pressure upon the beleaguered counterparts within IACs. It is likely that developing economies rich in energy and natural resources will enhance their role in the provision of ores and metals to domestic, regional and IAC markets, depending on the metal in the medium to long run. Despite the political and strategic desirability of retaining certain mining and processing operations within the confines of IACs, geological and technological factors mitigate against undue optimism in this area. In so far as specific ores and metals will remain important to the functioning of IACs, import dependence will remain and possibly increase, unless radical new processing technologies can be applied to the domestic refining and processing of traditional materials.

(b) Realignment of resource base

The foundations of industrial capitalism remain firmly rooted in the mineral base for the provision of structural and functional materials and energy. Dependence on the elements of the periodic table continues despite the increasing ability to synthesize. There is a larger number of elements and ores which can be processed into economically and functionally useful forms. This enlargement of the resource base which is integral to the progressive transformations undergone by the productive forces has been an ongoing process for the last one hundred years. The materials revolution has also brought into the limelight a large array of specialty metals such as zirconium, columbium, gallium, germanium, and many other rare elements which are used in small quantities in comparison to tonnage metals. They impart specialized properties to alloy systems and chemical compounds, thus leading to product differentiation and high-value-added entirely appropriate to meet the strategy of market niching as well as the high-performance requirements of intermediate and end-user industries in the 1980s. Specialty and minor metals including gold, silver and the platinum-group metals have displayed rapid growth in recent years and are expected to continue to do so.

Figure 8. The generic impact of the revolution in materials science and engineering in the structure of production



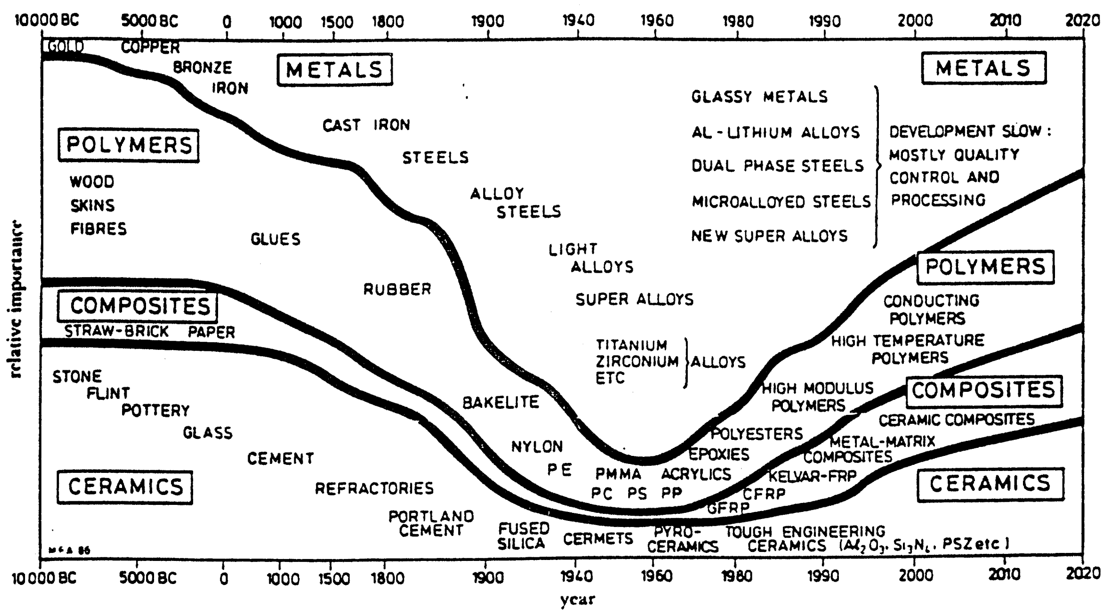
Source: L.C. Kaounides, 1992.

This national and global restructuring of basic traditional materials industries has been accompanied by a technological and corporate emphasis on downstream processing and fabrication techniques for metals, engineering plastics, ceramics and their composites. In the case of metals, this shift is associated with a move away from the first stage of processing towards the second stage, i.e. high-value-added, semi-fabricated, rolled, stamped, drawn and other types of products. It also involves new techniques such as continuous casting, powder metallurgy and rapid solidification aimed at near net shape manufacturing of advanced metallic components and composite and laminate systems for specific end-user applications. The application of advanced surface-improving technologies and coatings to enhance the properties of traditional metals is another highly significant trend.

Similarly, the processing of basic petrochemical inputs into carbon fibres, resins and other polymerized inputs acquire increasing significance. Apart from the central importance of fabrication techniques for specialties and composites, the ability to produce PAN (polyacronitrile) carbon fibres, an area in which Japan dominates, has become a strategic processing stage (see figure 12). The processing of special powders for the fabrication of ceramic components and composites and the processing of silicon into ultra-pure glass are also examples of the rising importance of processing and fabrication technologies for the manufacture of new knowledge-intensive advanced materials used in complex technologies and products.

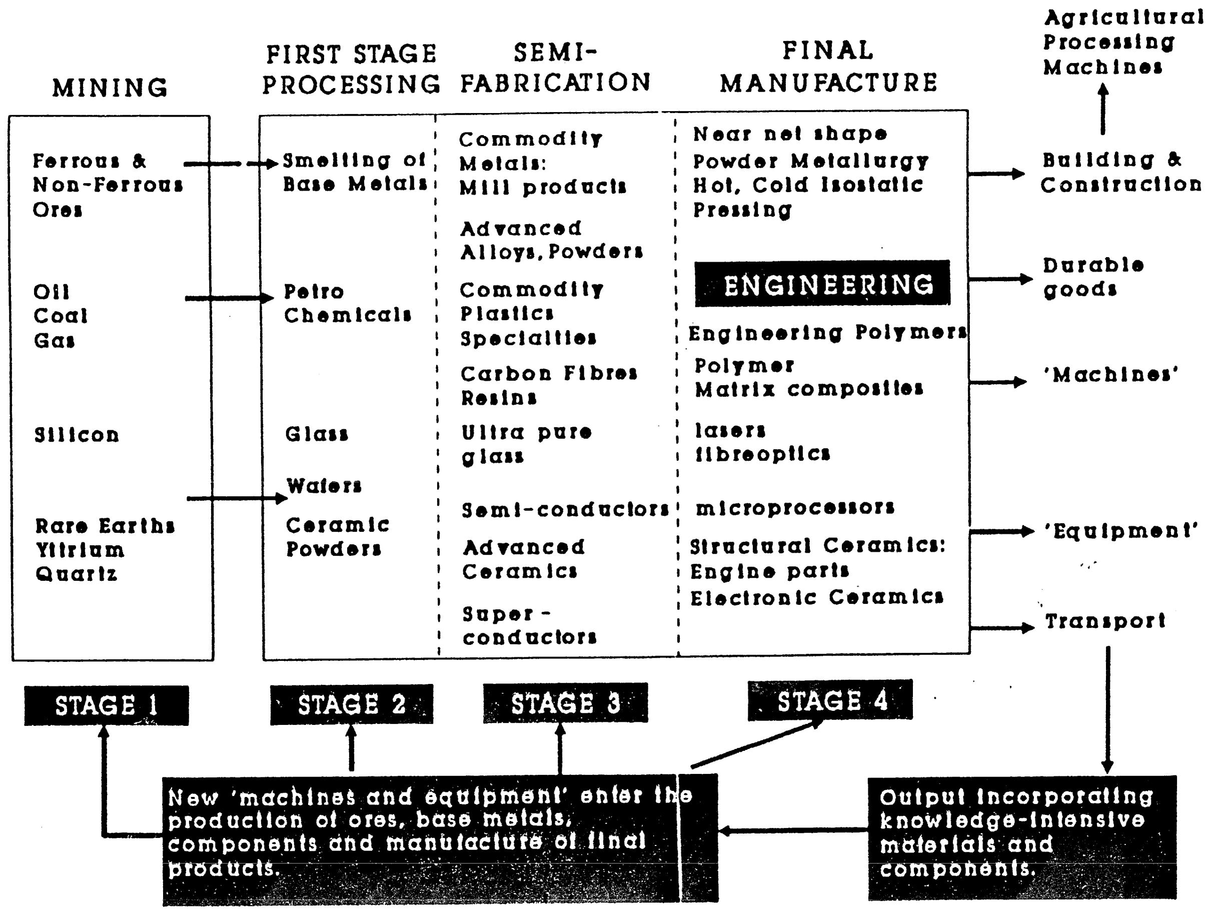
Figure 9. Evolution of engineering materials

The evolution of materials for mechanical and civil engineering. The relative importance of four classes of materials (polymers, composites and ceramics) is shown as a function of time. The diagram is, of course, schematic, and does not describe either tonnage or value. The timescale is non-linear.



Source: M.F. Ashby, *Philosophical Transactions of the Royal Society of London*, vol. 322, July 1987.

Figure 10. The emerging new materials economy



Source: L.C. Kaounides, 1992.

(c) Reduction of processing and assembly steps

The new processing and fabrication technologies (see, for example, figure 11) entail a reduction in or elimination of intermediate steps in the transformation of the material and its incorporation into end-products. As per figures 8 and 10, in a number of cases, an integration of steps between stages 2 and 3 is involved; in almost all cases, an organizational and technological integration is required between those stages and elements of end-user design and manufacturing processes within stage 4. This is both a process of contraction of sequential steps and an integration with the production of final goods. New advanced materials and new fabrication technologies not only address the need to eliminate costly and wasteful machining operations but also meet the need for simplification and ease of manufacturing and assembly operations in user industries. They therefore lead to a redesign of both product and processing, manufacturing or assembly operations.

A related point here is the emerging trend towards the early integration of materials into product design in manufacture. Materials-based, CAD (computer-aided design) product design and CAM/CAE (computer-aided manufacturing/computer-aided engineering) are a radical departure from past design experiences. Materials science is implanted in the product design and manufacturing process in user industries, thus engendering great advantages in the speed of successful product innovation under new market conditions.

This greater role of materials in the process of product design and manufacturing means that all materials industries in the 1980s and 1990s have to forge greater links with end-user performance specifications and requirements. This closer attention and integration of materials development to end-user needs is a central feature of inter-materials competition and will place increasing demands on the materials sector to engineer specific materials or materials systems or combinations to meet user performance criteria. Hence, end-user specifications are becoming critical determinants of the evolution, organization and speed of change across the materials field. Viewed from this angle, end-user or market-determined materials requirements also entail close collaboration between user and producer in material selection and development. They also exert pressure for downstream integration, formal or informal links, and, in-house acquisition of materials knowledge, skills and capabilities on the side of users. Such trends do not reside in mere speculation but are already a well-entrenched and prominent feature of change in manufacturing through IACs. The emerging trends toward world-class manufacturing fully endorse, incorporate and necessitate the tendencies enumerated above.[9]

(d) The emergence of materials firms and industries

The transformations under way at the basic-industry level of an economic system are ushering in a fundamental break with the past, relatively clear demarcation lines between dominant materials such as metals and plastics, "their" markets and the process of substitution between them. Industries and firms are moving away from the narrow specialized capabilities of a specific metal or material and are, of necessity, acquiring multimaterial capabilities. In fact, metals industries now recognize that they are producing "quality and performance" and not a specific metal. As such, they have become "materials industries" rather than metal or

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[9] See chapter IV for a discussion of materials-based simultaneous manufacture.

chemical producers. Moreover, quality rather than cost is becoming the overriding criterion in materials selection.

At the level of the input producing stages of production (1 to 3), a number of distinct clusters of materials have emerged: metals, ceramics and polymers and their composites, comprising thousands of different products, all competing to satisfy the performance specifications of engineering, structural and functional applications. The clear lines between metals (and the limitations of their properties as a constraint in end-use development), during the era in which the productive system was predominantly metal-based, have now been replaced by multimaterial capabilities with significant interpenetration of end use. The starting point today is not a pre-existing metal with specific properties around which a structure is designed, but rather the specific agglomeration of end-use characteristics and performance requirements and hence the development of a material or combinations of materials appropriate for that need. This is made possible by the fact that the entire materials sector is permeated by the scientific and technological capabilities of the materials advances, as shown in figures 8 and 10. Thus, those branches of industry engaged in the processing, transformation and fabrication of materials have acquired an expanded scientific and engineering base allowing existing materials and processing techniques to be radically upgraded and entirely new materials to be synthesized and combined synergistically. Metals, chemicals, ceramics, glass, and other materials firms are utilizing existing strengths and knowledge in their traditional occupations, moving downstream, transposing their basic products into the age of advanced materials specifications and applications and acquiring strengths in related materials business, internally and externally, via joint ventures, mergers, acquisitions, technology licensing and cross-border strategic alliances and joint research programmes.

Hence, the materials sector in the late 1980s and early 1990s is very different from that dominating the productive system hitherto. The clear delineations, conservative attitudes and limited capabilities of the past have given way to almost unlimited possibilities, proliferation and acceleration of new materials as well as a blurring of intra- and inter-material divisions with a marked ability to customize materials, no matter what their origins, to meet specifications in various markets. The metals economy has given way to the materials economy, of which advanced materials are a leading and fast- growing segment. Moreover, the analysis in section A leads us to the stronger proposition that all classes of materials can now be viewed as "new materials" with vastly enhanced scientific and processing capabilities.

III. THE GLOBAL RESTRUCTURING OF BASIC INDUSTRIES, 1970s-1990s

In terms of demand, commodity metals and chemicals experienced the first signs of a marked saturation of several of their end-product markets in the early 1970s, together with the deceleration of aggregate economic activity, the relative decline of materials intensive durable goods production, and the severe recession of 1975. The latter had been preceded by the sharp upswing of 1973-1974 which led to serious commodity shortages world-wide and a consequent escalation of prices. As for costs, the pre-eminent event was the large rise in the price of energy in 1973 which greatly affected the cost structure of energy-intensive metal and chemicals production, the feedstock of the latter mainly based on oil. The rise in energy costs combined with increasing labour costs and, importantly, the need to comply with ever more stringent environmental regulations, which imposed heavy capital expenditures on producers in their effort to retrofit existing capacity. These pressures have rendered increasingly uneconomical both old, inefficient technologies embodied in sunk capital as well as the establishment of the new Greenfield smelting capacity for purposes of replacement or expansion within the industrial structure of IACs.

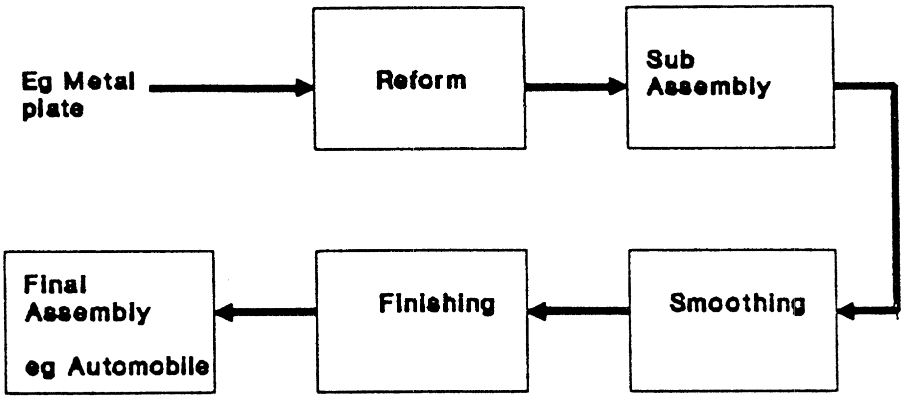
It was in the 1970s that the decline and redeployment of basic industries within the Organization for Economic Cooperation and Development (OECD) began. Primary metal and petrochemical capacity in developing energy- and resource-rich but pollution-intensive economies rose substantially, both in response to changing comparative advantage and as a deliberate policy instrument pursued by third-world States. Import penetration by cheaper commodity metals, such as steel, aluminium and copper, and petrochemicals further exacerbated the structural problems faced by basic industries within the IACs in the late 1970s and 1980s. Remarkably, during this period in which structural changes of a fundamental nature on the cost and production side and on the demand side were setting in, most industries were still basing their demand projections, and hence capacity expansion plans, on simplistic extrapolations of pre-1973 trend growth rates, refusing to believe that the 1975 recession had been anything more than a cyclical downturn (see figure 13). The price of this expansion of global capacity was paid in the 1980s. It was only in recent years that producers in basic industries recognized the need for radical measures to meet fundamentally new market conditions dawned on producers in basic industries. However, the lessons of the early 1980s in basic petrochemicals were all but forgotten by the late 1980s, with large capacity expansions coming on stream by 1992 in European ethylene production.

A. Ferrous and non-ferrous metals

In the 1980s, the world mining and primary-metals sectors experienced a prolonged period of depressed prices, serious decline in demand, financial losses and fierce competition in the midst of large overcapacity. During 1985 and 1986 the prices of several major metals fell, in constant dollars, to levels prevailing in the 1930s. Naturally, the severity of the recession impacted unevenly on minerals and industrial branches within national economies. Nevertheless, all mining and metals branches underwent deep restructuring. Old and inefficient capacity was permanently closed, labour contracts were renegotiated, employment was reduced and remaining capacity modernized. The rationalization measures have resulted in lower average costs globally in each branch as well as shifts in the relative competitive position of national branches on the cost or supply curve.

With the focus on the important materials industry in the United States of America, key strategies are clearly identifiable in the fight for survival and profitability in mining and metals. Firstly, a major cost-cutting effort is under way. Domestically owned, high-cost, inefficient and obsolete capacity has been shut down. The remainder has been modernized or rebuilt. Plant closures in the United States mining and metals industry led to a loss of 492,000 jobs between 1981 and 1987 (i.e., 46% of the decline in all manufacturing jobs!). Interestingly, although fewer production workers remain, more flexible collective bargaining agreements have been negotiated, and workers today are multiskilled and are expected to perform a greater variety of tasks as well as impart greater efficiency and value to the products. Employment trends are shown in figure 14.

Figure 11. Durable goods design: net shape processing with polymeric materials



Traditional Materials

- High Strength
- Low Cost
- Constant Shape

Non-Traditional Materials

- Low Strength
- High Cost
- Variable Shape

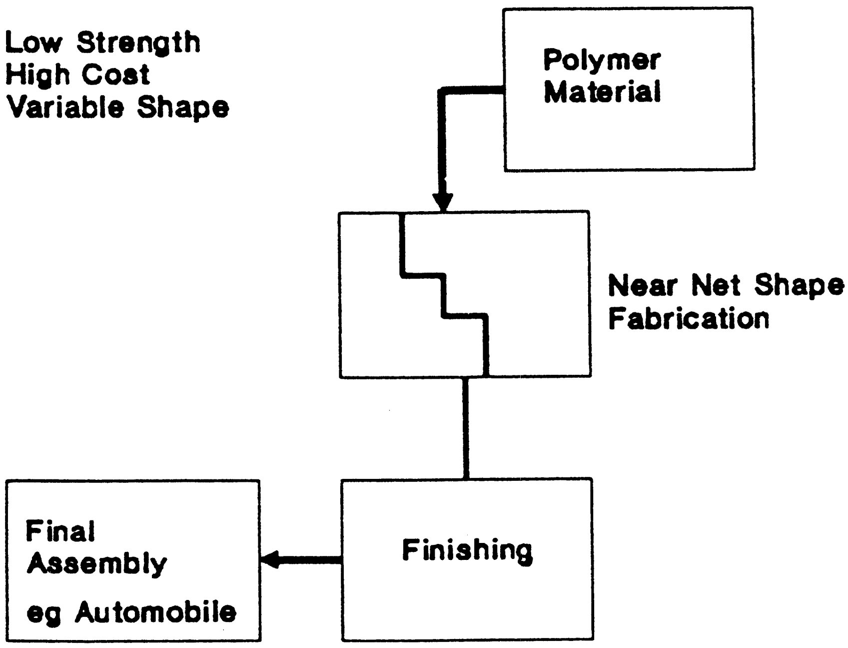
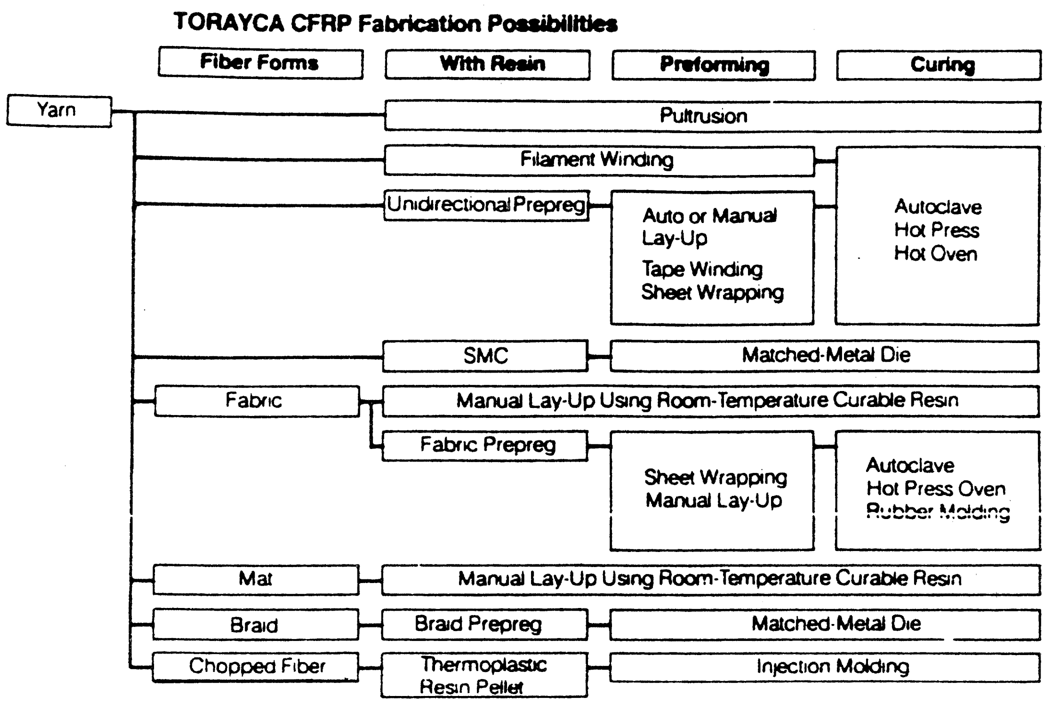


Figure 12. Fabrication of fibre-reinforced composites at Toray



Source: Toray Industries.

Secondly, metals companies have been moving downstream to higher-value-added production and are beginning to reduce their dependence on the "commodity" metal stage of the industry where profits are being squeezed and competition from low-cost overseas suppliers is high. Thus, some companies are purchasing imported ingots, reducing domestic smelting and moving into higher-value-added, more specialized materials production. Together with this strategy, there is a much stronger emphasis on marketing, product quality, and customer service. This closer attention to demand and integration with the customer is a marked tendency in all materials industries.

Thirdly, metals industries are diversifying into new and related businesses, including advanced materials such as new alloys and composites, aimed at high-growth market segments.

The combination of these measures resulted in a smaller but more efficient, viable and restructured primary metals industry in the late 1980s which bore little resemblance to what it had been at the beginning of the decade. Mining and primary metals industries have responded technologically and organizationally to higher costs, declining profits and competition from imports.

A marked improvement in profitability resulted from the continuation of modernization and cost-cutting efforts together with improved market circumstances that witnessed a significant rise in copper prices, which had been depressed in real terms since the mid-1970s.

1. *Aluminium*

The debilitatingly high cost of energy has decimated the primary aluminium industry in Japan. From an all-time high of 1.6 million tonnes of smelting capacity in the late 1970s, with seven companies and plants, by 1985, this was reduced to 220,000 tonnes, four companies and four plants. Today, smelting capacity is less than 15,000 tonnes!

Nevertheless, while domestic smelting plants have been rendered uneconomical and obsolescent, the increasing demand for aluminium in the Japanese economy has been met by imports. In fact, Japan has become the largest importer of aluminium in the world. Most of the demand, though, is not met from the spot market, but rather from overseas aluminium projects which have resulted from joint ventures by Japanese companies to acquire strategic positions in overseas mining and smelting operations, given either a total lack of domestic resources, such as bauxite, or increasingly unviable domestic mining and smelting operations, as has been the case throughout the 1970s and 1980s.

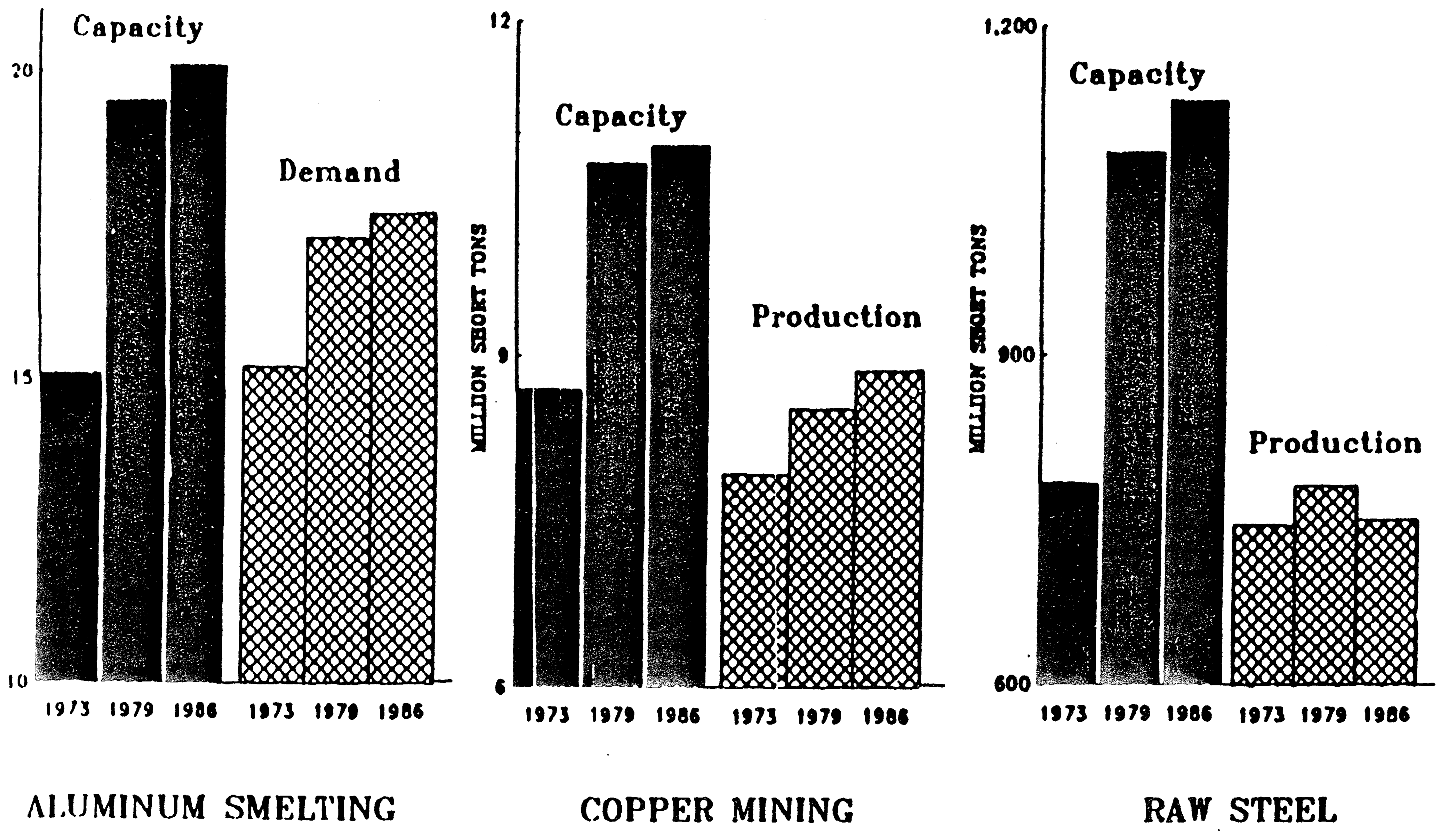
As aluminium production was declining in the 1980s, the demand for semi-fabricated and rolled aluminium products continued to grow. Production of rolled products increased to an all-time high of 1.7 million tonnes in 1985.

In the United States, the aluminium industry has reduced corporate employment by 25 to 40%, closed inefficient capacity, and modernized and technologically upgraded high-value-added fabricating operations. The net result of such efforts has been a cumulative reduction in costs and an increase in the competitiveness of the remaining aluminium industry. Figure 15 indicates the decline of the average unweighted operating costs of the three largest United States producers between 1984 and 1986. Employment, productivity and profitability in United States aluminium is shown in figure 16.

2. *Copper*

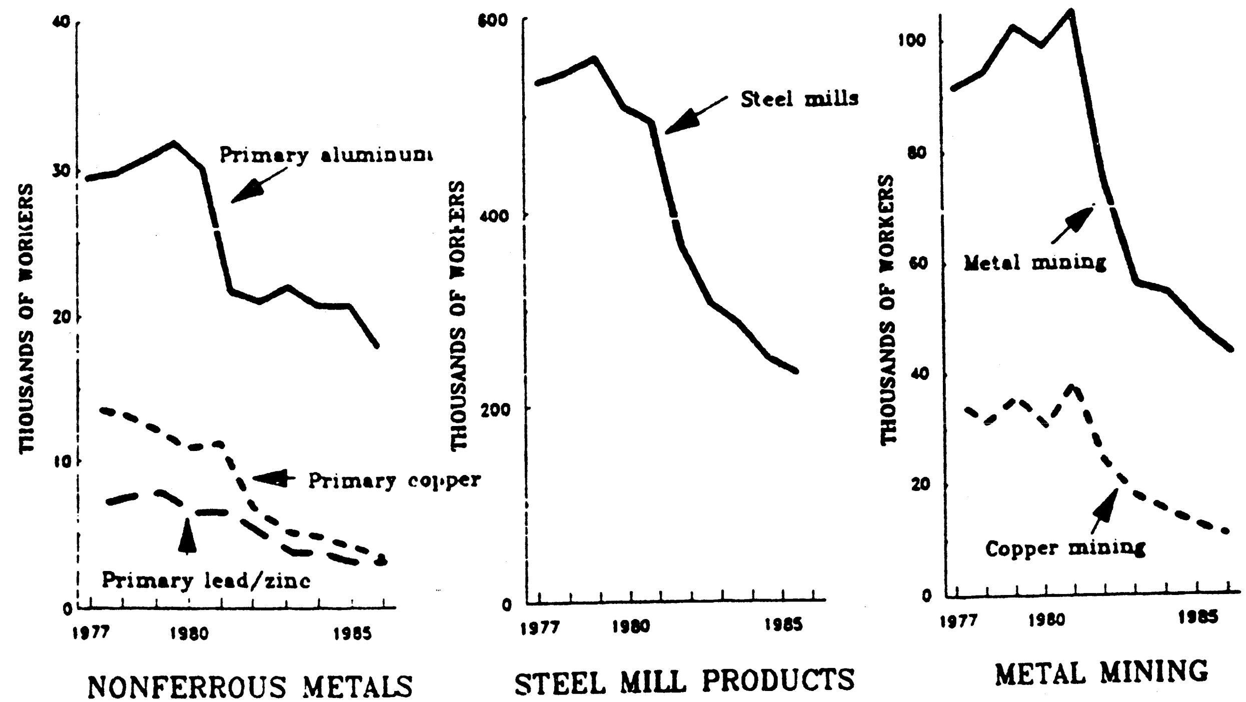
The United States copper industry has in recent years undergone substantial reorganization and restructuring which have markedly improved performance and prospects over the short- to medium-run. Several mines have been closed, put on a reduced schedule or sold off to integrated producers, while much labour has been eliminated and labour contracts renegotiated. Mining costs have been further reduced by dramatic improvements in stripping ratios and a switch to higher grade ore. However, the central determinant of the remarkable turnaround in productivity and cost reduction has been new technology in the areas of material handling. This involves the use of continuous conveying and computerization of truck dispatching, massive in-pit crushing equipment, and especially heap-leaching solvent extraction and the modern SX/EW electrowinning technology, which by 1988 produced the cheapest copper in the world, at around 30 cents per pound. Further downstream, rationalization of smelters and refineries has resulted in the premature closing of many older, inefficient plants. Remaining smelters have been upgraded through investment in state-of-the-art flash-smelting technology, as indicated in figures 7 and 8.

Figure 13. Growth in world capacity vs. growth in world demand/production



Source: L. Sousa, Problems and Opportunities in Metals and Materials: an Integrated Perspective, U.S. Bureau of Mines, 1988.

Figure 14. Employment trends in the United States metals industries



Source: L.J. Sousa, U.S. Bureau of Mines, 1988.

In 1992, the global copper industry experienced a tight supply situation due to shortages in smelting capacity, with prices expected to reflect this over the next two years (around $1.00-$1.10 in 1992, $1.25-$1.40 in 1993 and $1.30-$1.50 in 1994). Investment in new smelters is difficult to justify at the moment due to an inadequate rate of return on capital. The building of new copper smelters in recent years has been for political or strategic reasons, and this is expected to continue, maintaining the tight supply situation.

3. *Steel*

(a) The European Community

In the steel industry of the European Community (EC), the labour force has been halved since 1976 (see figure 19), and over 30 million tonnes of capacity was eliminated between 1980 and 1986. Nevertheless, there is still an annual excess capacity of 47 million tonnes within the EC, which implies that the painful restructuring of the 1980s is not at an end. At the same time, Europe's steel producers have improved productivity and have begun to forge closer links with users in industry, such that over two thirds of EC steel is tailor-made to customer needs. Car manufacturers, for example, now demand flawless materials for just-in-time delivery and production. Hence steelmakers must closely cooperate with industrial users to develop the highest quality materials and processing technologies to meet customer specifications in end products. Commodity steel products such as heavy plates and wire rods are being relinquished as EC steel producers, in common with their American and Japanese counterparts, are moving to higher-value-added and more specialized products, such as higher-grade carbon steels, stainless steel, galvanized sheets and high-technology specialties.

(b) Japan

In Japan, the five largest steelmakers (Nippon Steel, Nippon Kokan, Kawasaki Steel, Sumitomo Metal Industries and Kobe Steel) were aiming to shut down 8 of the country's 34 blast furnaces by 1990. The industry as a whole has been automating and cutting capacity such that the labour force has been reduced by 47,000 since 1986 to a remaining total of just under 300,000. The pronounced move to higher-margin products and specialities by Japanese steelmakers, together with the expected mastering of new mini-mill speciality technologies by other firms in the region, such as Pohang Iron in the Republic of Korea and Anfang and Yie United of Taiwan Province of China signifies an impending export drive to western markets and an intensification of competitive pressures. European producers are bracing themselves against this looming threat, adopting such defensive measures as cross-border mergers, acquisitions and joint ventures.

There is also clear evidence that Japanese steelmakers and other traditional materials producers have diversified into related and advanced materials areas at an accelerated pace in recent years. Table 1 presents the results of the latest MITI (Ministry of International Trade and Industry) survey. The evidence points to both materials producers and users employing new materials at an increasing rate.

(c) The United States of America

In the early 1980s, the United States steel industry was one of the least efficient in the world under threat from imports. In the last decade, the industry embarked on a process of rationalization and radical restructuring which involved the closure of dozens of inefficient plants, the halving of the workforce, and a massive capital expenditure (over $20 billion) to modernize and technologically upgrade existing plants. Average man-hours per tonne of steel fell continually from nearly 11 in 1980 to just below 5 by 1991. At the same time, Big Steel benefited from Voluntary Restraint Agreements (VRAs) in force since the early 1980s in order to provide time for United States producers to modernize. On 10 August 1992, the United States International Trade Commission considered further complaints by Big Steel that it was being subjected to unfair dumping of foreign steel from companies heavily subsidized by their Governments. In fact, the weak dollar in recent years has actually led to a decline in steel imports to the United States market. Furthermore, United States Big Steel has benefited considerably in recent years from capital injections and technological assistance from Japanese steel producers (see table 3) which have overcome trade barriers by forcing joint ventures with United States producers. Nevertheless, the large United States steel producers face serious problems in the early 1990s, continuing to lose money as they have done for over a decade. The United States recession has sharply curtailed the domestic demand for steel, and the global oversupply of steel has reduced prices to 1980 levels, or lower in real terms.

The technological and organizational threat of mini-mills

The large, vertically integrated United States steel producers engaged in the transformation of iron ore into finished steel products (table 4) face a potentially devastating threat from the rise of mini-mills. Mini-mills[10] have developed in the last three decades and have begun to make inroads into traditional markets for bars, wire and rod, long the province of Big Steel. Mini-mills now account for 21% of United States steel consumption as compared to 17% taken by imports. The flat organizational structure, non-union labour force, and less capital-intensive technology which they employ has provided mini-mills with large cost advantages in markets for low-grade steel products. Big Steel has responded by moving to higher-value-added, higher-margin, more technologically sophisticated markets (about half of United States consumption) for flat rolled products. Nevertheless, Nucor is the first mini-mill to make flat rolled products, at the lower end of sophistication, by a thin-slab casting technique which promises to shake up the steel industry in the coming years. The advantage of the method is that it takes less time, far less energy and far less capital spending on rolling equipment.

B. The politics of the decline of smokestack industries

It is important to recognize that the traditional basic industries such as aluminium, steels, alloys and cement will still be needed well into the next century. Increasing demands will be made on them not only to meet the needs of more advanced applications throughout industry, but also in less sophisticated applications such as infrastructure and construction. This implies that in global terms there will still be the matter of the adequacy of the resource base

[10] See *Financial Times*, 7 August 1992.

and the issue of the interplay between technical change and depletion of economically recoverable ores. The traditional resource base will therefore retain its importance to a large extent, although over time the relative position of individual metal industries will change due to shifts in demand and mining costs.

In the context of national economies, therefore, the issue of retaining technologically efficient and healthy traditional mining and basic industrial branches, heavily influenced by strategic, political, technological and economic considerations, versus their gradual decline and relocation abroad, will continue to loom large for several years. The geographic dispersion of economically recoverable ores, together with the ore grade and cost conditions at work within IACs, ensure the continuing import dependence (see figures 25 and 26) of the United States, the European Economic Community (EEC), and Japan on a whole array of strategic and critical ores and metals, despite technological efforts[11] to reduce such dependence. Some view the decline traditional mining and processing activities within the industrial structure of IACs and their relocation to third-world countries as inevitable. In fact, this is seen as a major reason for the need of IACs to deliberately shift their industrial activities towards higher-value-added, knowledge-intensive, up-market activities. This inevitable decline of basic industries and their expulsion to developing regions of the world highlights "the crucial need for developed countries to embrace the new technologies and to venture into products with high value-added that incorporate advanced materials. In the fields of mechanical and electronic engineering, a prerequisite is the availability of materials with novel characteristics or a combination of unique properties—for example, light, strong, polymer composites, corrosion-resistant plastics, and temperature-resistant, toughened ceramic materials—for up-market products."[12]

The speed and mechanisms for dealing with this process of structural decline of traditional industrial branches with IACs differ from one economy to another. The Japanese Industrial Structure Council has adopted a planned approach to the decline of energy-intensive basic industries (see table 4), while companies have been relocating facilities abroad, entering into joint ventures and long-term contracts, all the while moving further downstream and embracing advanced materials activities at home. On the other hand, the loss of a sizeable chunk or, worse, the complete disappearance of important basic metals and petrochemicals branches within the EEC and the United States, is not a politically acceptable option, despite the recognition of the importance of new and advanced materials in sophisticated applications as a crucially important technology for national competitiveness. Hence, over the next 10 years or more there is likely to be a struggle to continue to technologically upgrade and modernize domestic mining and processing activities in traditional materials, especially since production costs are the critical factor in the competitive position of these industries. At the same time, such economies will shift their industrial structure towards the production and use of advanced materials.

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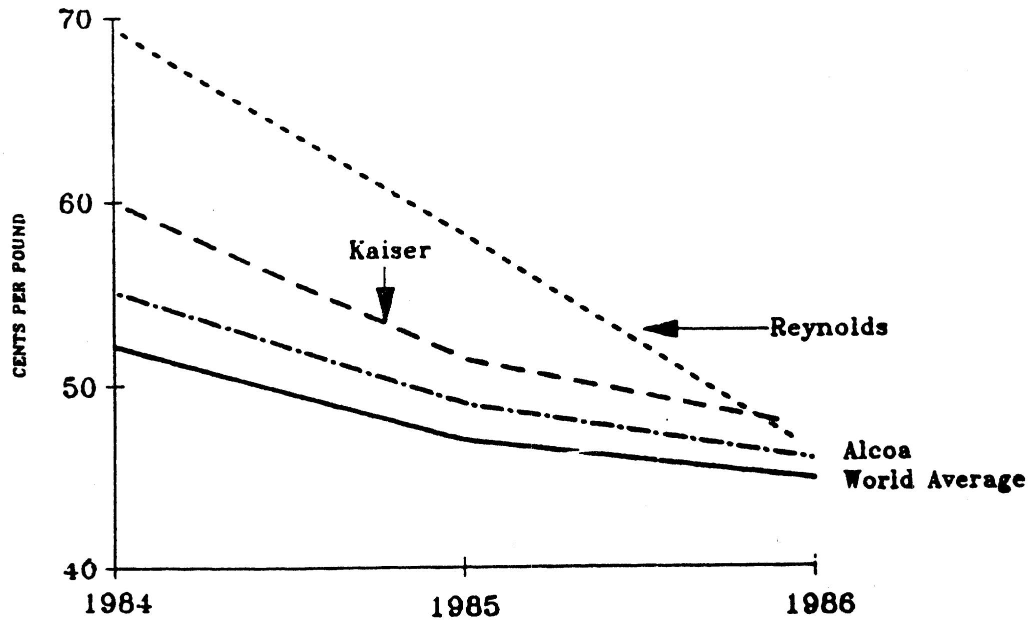
[11] Strategic Materials: Technologies to Reduce United States Import Vulnerability, United States Congress, Office of Technology Assessment (OTA), May 1985, and Potential of Ceramic Materials to Replace Cobalt, Chromium, Manganese, and Platinum in Critical Applications, MIT study for OTA, January 1984.

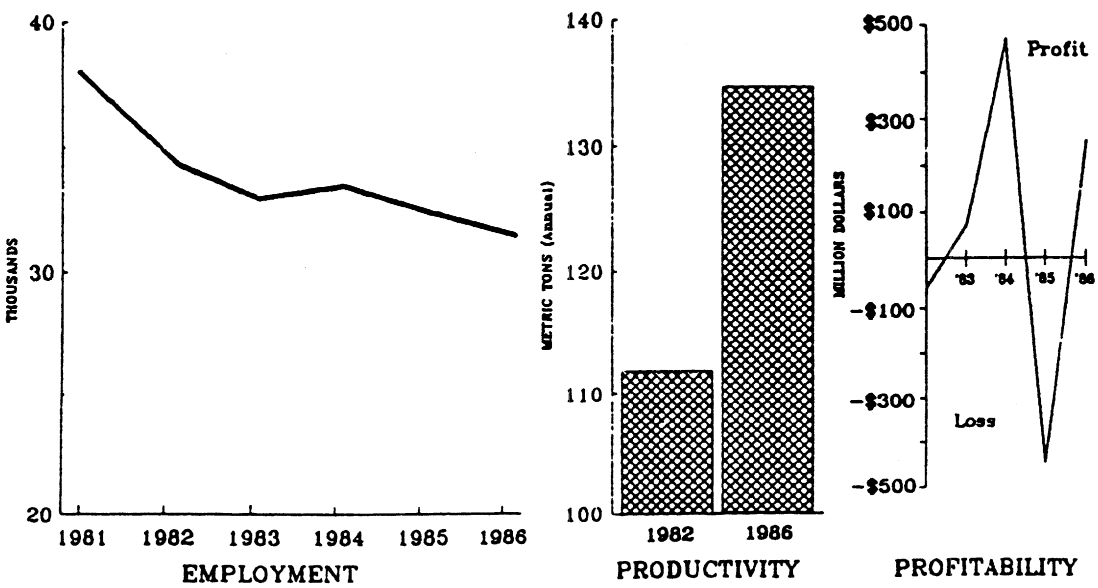
[12] E.D. Hondros, Director, EC Research Centre, Petten, in *The Materials Revolution*, Tom Forester (ed.), Basil Blackwell, 1988.

Figure 15. Aluminium production costs of three major United States producers and world average, 1984-1986



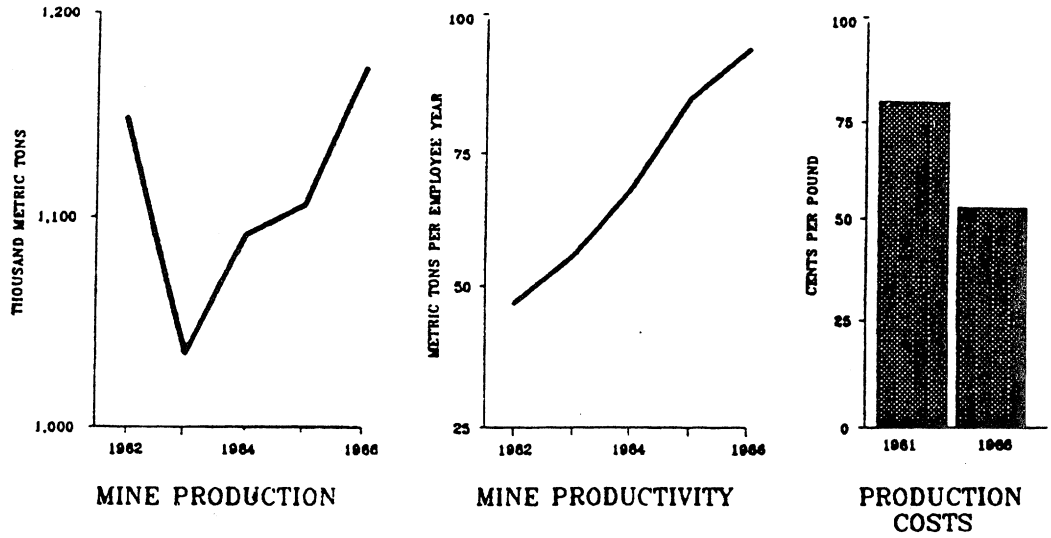
Source: The Mineral Position of the United States, 1987.

Figure 16. Employment and productivity in aluminium smelting, profitability in the aluminium industry



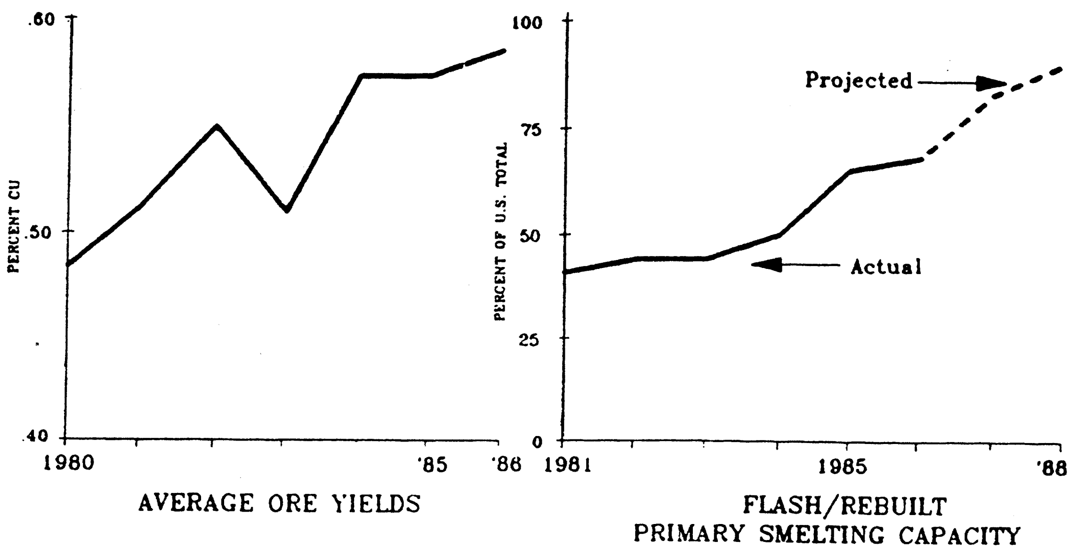
Source: L. Sousa, 1988.

Figure 17. Recent trends in the United States copper industry: production, productivity, costs



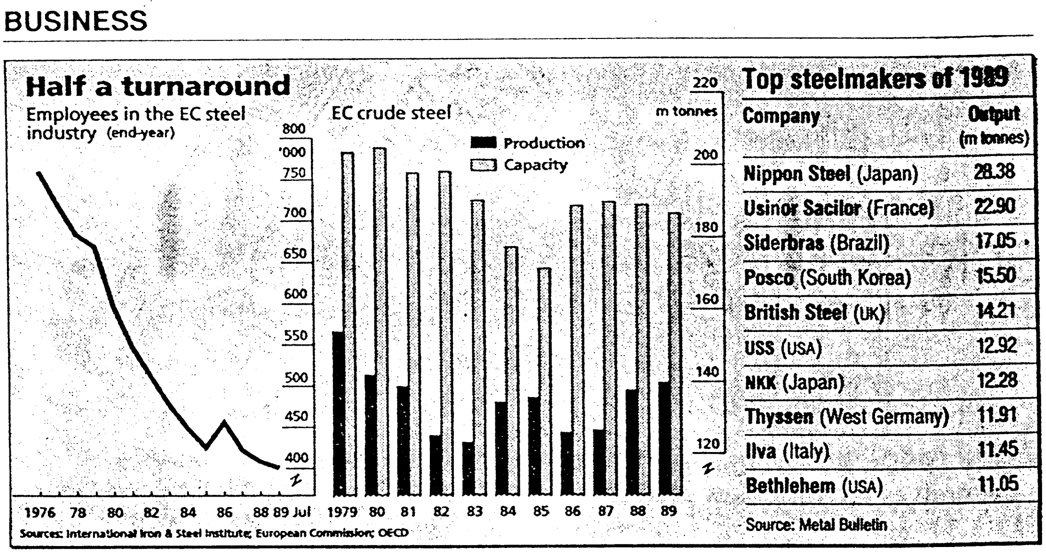
Source: L. Sousa, 1988.

Figure 18. Recent trends in United States copper mining and smelting



Source: L. Sousa, 1988.

Figure 19. The European Community steel industry trends



Company	Output (m tonnes)
Nippon Steel (Japan)	28.38
Usinor Sacilor (France)	22.90
Siderbras (Brazil)	17.05
Posco (South Korea)	15.50
British Steel (UK)	14.21
USS (USA)	12.92
NKK (Japan)	12.28
Thyssen (West Germany)	11.91
Ilva (Italy)	11.45
Bethlehem (USA)	11.05

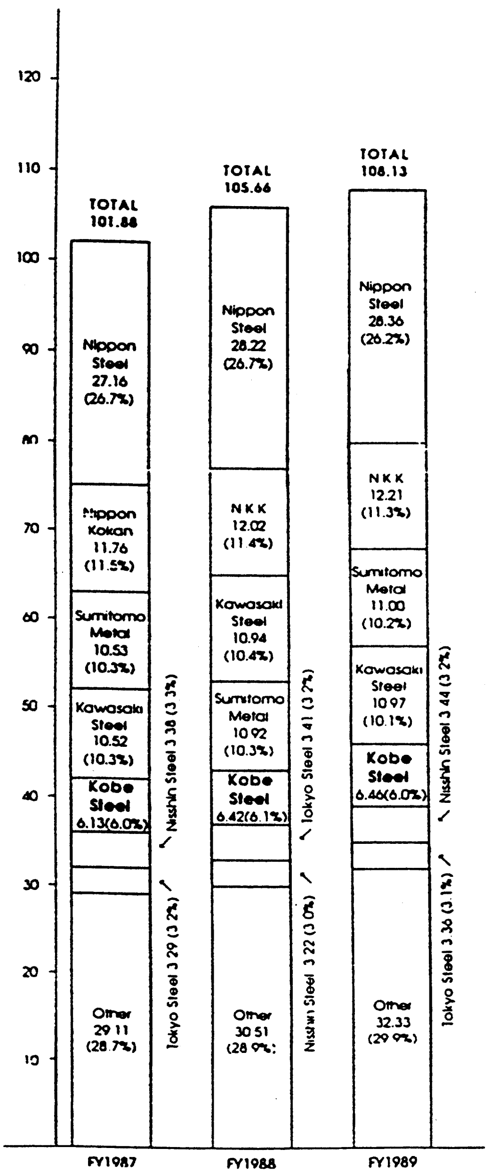
Source: The Economist, 10 March 1990.

In this regard, it is worth while to note the comments of a senior member of the Science, Space and Technology Committee of the United States House of Representatives in a speech to the House on 18 May 1987: After recognizing the concern engendered by the fact that the United States had been and continued to be highly dependent on the import of key materials, including cobalt, chromium, platinum, and manganese—all of which were imported at levels exceeding 90% of consumption—he went on to describe how Congress had responded to this concern with the enactment of the National Materials and Minerals Policy Act of 1980 (Public Law 96-479), the first legislative vehicle in more than three decades to address materials policy concerns broadly. He noted that the law had been seen as only a first step which attempted to focus attention on the importance of regarding materials but had not been intended as a final solution to the problems of the United States; rather, it was viewed as a means of understanding and addressing those problems.

He underscored the critical importance of advanced materials and related technologies, as well as basic materials, in the nation's ability to compete in the international market-place and noted that Japan, Western Europe and others had taken decisive steps towards developing key advanced materials technologies designed to leapfrog the economic prominence of the United States.

Figure 20. Japanese crude-steel production

Japanese Crude Steel Production
(in millions of metric tons)



Sources: Kobe Steel.

Largest Steelmakers In The World
(in millions of metric tons)

	Steelmaker	Country	1989	1988
1	Nippon Steel	Japan	28.4	28.3
2	Usinor-Sacilor	France	23.0	17.6
3	Pohan Steel	Korea	15.5	13.1
4	British Steel	U.K.	14.2	14.7
5	USX	U.S.A.	12.9	14.1
6	NKK	Japan	12.3	12.0
7	Thyssen Stahl	F.R. Germany	11.6	11.8
8	ILVA	Italy	11.4	11.8
9	Bethlehem Steel	U.S.A.	11.1	11.7
10	Kawasaki Steel	Japan	11.0	10.9
11	Sumitomo Metal	Japan	11.0	11.0
12	SAIL	India	8.5	8.4
13	LTV	U.S.A.	7.7	9.5
14	ISCOR	South Africa	7.0	6.3
15	**Kobe Steel**	**Japan**	**6.5**	**6.5**
16	BHP	Australia	6.3	6.0
17	China Steel	Taiwan	6.0	5.6
18	Hoogovens	Netherlands	5.4	5.3
19	Inland Steel	U.S.A.	5.0	5.6
20	Armco	U.S.A.	5.0	5.2
21	National Steel	U.S.A.	4.9	4.9
22	Krupp Stahl	F.R. Germany	4.6	4.3
23	Voest-Alpine	Austria	4.5	4.4
24	Peine-Salzgitter	F.R. Germany	4.4	4.3
25	USIMINAS	Brazil	4.4	4.2
26	Cockerill-Sambre	Belgium	4.4	4.5
27	Stelco	Canada	4.3	4.1
28	Hoesch	F.R. Germany	4.1	4.1
29	Dofasco	Canada	4.0	3.7
30	ENSIDESA	Spain	4.0	3.3
31	ARBED	Luxemburg	3.7	3.7
32	Klöckner-Werke	F.R. Germany	3.6	3.6

Notes: The largest amount of crude steel produced was 120 million metric tonnes in fiscal 1973. The lowest amount in the last 10 years was in fiscal 1982 at 96.3 million metric tonnes.

Table 1. Entry into new materials by Japanese industry, 1985-1988

	1985	1988	1988/1985
Producers			
Chemicals	33	67	2.0
Glass/Ceramics	12	35	2.9
Non-ferrous metals	11	27	2.5
Steel	15	24	1.4
Textile	7	20	2.9
Petroleum/Rubber	5	12	2.4
Pulp/Paper	2	9	4.5
Subtotal	85	194	2.3
Users			
General machinery	0	20	--
Electric machinery	5	18	3.6
Transportation machinery	3	13	4.3
Precision machinery	0	11	--
Construction	0	4	--
Subtotal	8	66	8.3
Others	0	42	--
Total	93	302	3.2

Source: MITI.

Box 1. Case-study: the Japanese steel industry

A. Restructuring and diversification into electronics and new materials

The year 1985 marked a watershed in the evolution of the Japanese steel industry. The oil shock of 1973 gave rise to a prolonged period of slow growth in world consumption and production of crude steel. Following a record output of nearly 120 million tonnes in 1973, 111 million tonnes in 1980 and 105 million tonnes in 1984 and 1985, crude steel output in Japan fell to 98 million tonnes in 1986 and 1987. This was due to a domestic recession induced by the appreciation of the yen which was in turn triggered by the Group of Seven in September 1985. Both the steel industry itself and large steel-using industries such as automobiles, machinery, plants and shipbuilding, suffered a sharp drop in export competitiveness as a result. All five major steel producers registered large deficits during 1986, which led to the introduction and implementation of massive programmes of company-wide restructuring and rationalization. These measures were introduced in order to ensure the industry's profitability and financial viability even if crude output fell, as was predicted at the time, to 90 million tonnes per annum by 1990.

Nevertheless, the industry began to stage a recovery on the basis of healthier domestic demand from the second half of 1987 onwards. The industry entered 1987 facing dismal prospects, but by May the Government had introduced an emergency economic expansion package of about 6 trillion yen aimed at stimulating domestic demand. Fiscal measures were combined with monetary measures such as the lowering of the official discount rate to a post-war low of 2.5%, and these began to be felt in the economy by the second half of the year. Steel demand began to pick up following a boom in housing and office construction, government-induced public-works investment programmes, and sharp rises in steel demand from manufacturing industries catering to rising personal consumption expenditures. On the other hand, Japanese steel exports fell by 15.3% in 1987 due to stiff competition from the NIEs, a persistently high yen and a continuing shift to production overseas.

Crude-steel production rose to 105 million tonnes in 1988 while there was a dramatic turn-around in the performance and profitability of the major five steelmakers in the same year. This was due to the effect of the massive restructuring and rationalization measures, diversification, and the strong growth in steel demand led by continuing economic growth on the domestic front. Domestic, demand-led economic growth continued unabated in 1989, riding on a rising wave of personal consumption and business investment expenditures. Consequently, steel output rose to 107.9 million tonnes in that year, with steel companies recording their best results ever. The strength of domestic demand for steel persisted in 1990. Figures from the Industrial Bank of Japan for fiscal year (FY) 1990 predict a crude-steel output of 110 million tonnes which, given the yield rate improvement, translates into a final-steel figure of over 120 million tonnes surpassing the historic high of 1973. There were signs of a slow-down, however, in economic activity in fiscal 1991 as compared to fiscal 1990, following a reduction in housing starts, weaker private fixed-capital formation, and lower demand from manufacturing industries, led by automobile manufacturers. Counteracting this is the substantial (430 billion yen) public works as a result of the Japan-United States Structural Impediments Initiative talks; hence, steel demand is expected to remain at high levels (e.g., approximately 78 million tonnes for ordinary steel or over 95 million tonnes on a crude-steel basis) in fiscal 1991 albeit lower than the previous year.

(Continued)

The economic circumstances in which the steel industry found itself from the mid-1980s onwards, from the grim prospects of a recession due to the strong yen to the brisk domestic upswing ending in 1990, form the contradictory backdrop against which the process of deep restructuring and strategic re-orientation of activities into the next century is taking place. Although the signs of deep-rooted structural problems afflicting steel were evident from the early 1970s, and the industry was beginning to respond to them, it was the shock of the strong yen and the recession of 1985/1986 that spurred urgent action from steel firms with weak financial positions and long-run growth prospects as business entities. Such strategies needed to reflect the changing requirements of steel-using industries as well as the opportunities offered by the arrival of major new generic technologies such as microelectronics and new materials. The recession of 1991-1992 is now forcing the major steel producers to re-evaluate a number of non-core diversification moves undertaken in the euphoric conditions of 1989-1990. Production and income trends for 1988-1992 are shown in figure 21.

B. Rationalization, technological upgrading and emphasis on fine steels

The rationalization plans launched by the major steel producers between late 1986 and early 1987 included closures and consolidation of blast furnaces, basic oxygen furnaces, plate mills and pipe mills in order to reduce excess capacity and improve utilization rates.

The closure of facilities and the improvement in productivity caused large numbers of employees to become redundant, and measures to alleviate the problem become necessary, such as restrictions on overtime, transfer of workers among offices, secondment to other industries and affiliated companies, retraining, and transfers to new businesses. The number of employees in the sector declined from 338,000 in 1986 to 314,000 in 1987, 306,000 in 1988 and increased slightly to 307,000 in 1989.

Cost-cutting efforts combined with measures to strengthen the weak financial position of steel firms, which had relied heavily on debt financing in the past. Capital spending programmes were reviewed and were tightly controlled, centring on rationalization investments. Interest burdens were reduced through efforts to repay debt and shift to short-term borrowing to take advantage of lower interest rates. Warrant bonds and equity financing were used in order to obtain low-interest funds to repay loans.

C. New technologies to improve efficiency, competitiveness, flexibility and product sophistication

A major component of the rationalization measures under way since the mid-1980s and transcending mere cost-cutting is the strengthening of the existing steelmaking business through the introduction of new technologies. New technology and the incorporation of micro-electronics-based automation and control systems are necessary for cost minimization, greater flexibility in production processes and higher value added to steel products of higher sophistication. As with chemicals and other materials industries, steel is tackling the urgent task of upgrading product quality and adding higher value to products. The move to higher technological sophistication in products and processes is made essential by the increasingly stringent higher-grade requirements of downstream user industries and intensified competition from NIEs in existing product lines. Furthermore, a strong conventional steel base is viewed as the springboard for diversification into new and related high-growth business fields.

(Continued)

Improving production efficiency and quality

Technological improvements aiming at maximum efficiency in upstream operations (raw material treatment, iron-making, steelmaking and continuous casting) and downstream stages of production (rolling and processing) are being introduced at an increasing rate. Computer controls, artificial intelligence, measurement and control technologies, energy-saving technologies and laser applications have been introduced in order to improve efficiency and lead to high product quality.

The epoch-making CC process for semis has reached a saturation point in Japan. Consequently R&D efforts in this area are directed towards the shortening of the hot-rolling process to improve productivity, and also towards direct rolling and quality improvement through homogenizing component segregation. There is increased use of a horizontal CC process for small-lot production and higher-grade products.

In rolling, there are efforts under way to directly link CC and rolling, controlled rolling, controlled cooling technology and high-precision rolling technology. Advanced hot-process control technology, with strictly controlled accelerated cooling after rolling, has been developed, making possible the production of rolled steel products with harmonized strength and toughness without the subsequent addition of alloying elements and heat treatment. In sheet steel, a revolutionary continuous-annealing technology requires only 10 minutes to perform pickling and annealing, whereas conventional methods require 10 days! The technology was developed independently by Nippon Steel, NKK and Kawasaki Steel in Japan, with exclusive world-wide rights.

As part of their rationalization programmes from the mid-1980s onwards, the steel companies pushed even further the installation of facilities new surface-treating capacity. New investments focused on electrogalvanizing and continuous galvanizing lines and multi-purpose coating equipment. As a result, the ratio of surface-treated sheets to ordinary steel products continued to increase in order to meet rising demand for such products as customer requirements increasingly shifted towards higher-grade steels. With rising demand for higher-grade, higher-value-added products, cold-rolled wide-strip and galvanized-sheet output achieved all-time highs of 23.8 million and 12.3 million tonnes, respectively. Special steel orders broke through the 10-million-ton mark for the first time in 1989, with record orders coming from the automobile, industrial machinery and construction industries. Machine structured carbon steels, structural alloy steels and high-tensile-strength steel orders showed the greatest gains.

D. Materials science and engineering into steel-product developments

As Japan and other industrialized economies shift towards high technology and much higher levels of product and process sophistication, the steel industry has been forced to respond with products of much higher quality, especially with the advent of new materials encroaching on both traditional and new steel applications. The much better understanding of the structure-processing-properties continuum, the high-level characterization technologies and the cumulative knowledge residing in the steel industry have greatly improved characterization of higher-quality products. For example, in the past the heat treatment condition for steel of optimum properties was decided on the basis of experience; today,

(Continued)

however, scientific developments and measures as well as characterization technologies (with respect to material structure, elemental composition and chemical bond of the metal) enable such conditions to be predetermined. Lasers, wide application of optical fibres in steel mills and specific processes for measurement and control all play an important part in improving efficiency and product quality. Micro-alloying techniques are used to produce higher-quality steel, while emphasis is placed on steel products with the functional properties of fine steels.

1. *New product development*

As customer needs in user industries progressively become more diverse and demanding, the steel industry continues to increase the value of its products. Vibration-damping steel sheets are increasingly appearing in automobiles, buildings and household electrical appliances. In addition, sheet piling with a pleasing appearance and H-shapes with fixed outer dimensions have entered the market. TMCP (thermomechanically control process [sic]) plates have been approved as a building material and demand is expected to increase. New stainless-steel products and new types of stainless steel have been developed, with their application spreading in new fashionable designs and in automobiles, household electrical appliances and buildings.

2. *Joint R&D programmes for new-generation technologies*

The smelting-reduction process for iron-making typifies the next generation technologies in the process of commercialization. Joint research in this area began in 1988, carried out by the Smelting Reduction R&D Committee, with the participation of Japan's eight steelmakers, and a pilot plant was constructed in 1990. There are other joint research programmes under way which include the development of new processes for semi-solid processing, metallic materials with high-performance surfaces and new technologies for the production of materials for use in high-temperature, corrosive environments.

3. *Diversification into new businesses*

Together with the rationalization and strengthening of the steel business, the major steel producers are pursuing medium- to long-run plans for diversification into new, high-growth business fields. All five of the major blast-furnace steelmakers have unveiled medium- to long-term plans (table 2) which clearly indicate large-scale entry into new business fields in five major areas, namely: (a) new materials; (b) electronics, information processing and telecommunications; (c) the building of large-scale engineering projects, leisure activities and regional-development schemes; (d) service industries; and (e) biotechnologies. While the plans to eliminate excess capacity and reduce the workforce by 40,000 that were formulated under the conditions of the yen-induced recession were shelved by 1988-1989 due to strong domestic demand, the strategies for moving into new, high-growth fields have maintained their momentum. At the same time, serious labour shortages have manifested themselves and equity financing plans have faced difficulties due to the deterioration in the primary-securities market. Despite the excellent steel demand conditions from 1988 to 1990, the industry did not expect this situation to continue in the long run. The need therefore remains for the active development of new second- and third-generation business fields which will provide the foundations for the companies to grow sharply in the future, in the same way that steel

(Continued)

provided the mainstay for growth in the past. This has been confirmed by the events in the Japanese and global steel markets in 1991-1992. The main diversification areas of the major blast-furnace makers have been summarized in matrix form by the Industrial Bank of Japan (figure 22).

4. *Diversification into electronics*

Electronics and data communications are viewed as a critical core technology in the revolutionary transformation of Japanese industry and society into the next century, and hence they possess a very high market-growth potential. Steel firms point to considerable synergies between electronics and accumulated expertise in steel businesses, especially software development and micro-electronics applications, but this is not a view shared by all industry analysts. Steel firms have moved into software and hardware, the construction of LSI (large-scale integration) plants, the importing and marketing of United States-made supercomputers and the development and marketing of applications software for use in sales and business creations. For decades, steel producers viewed themselves as producers of Japan's "industrial rice", namely semiconductors.[13] This approach has been criticized within Japan, especially given current market conditions, but steel producers are determined to move into electronics.

Nippon Steel's view of synergy between existing steelmaking strengths and new business, including electronics, is shown in figures 23 and 24. The company does recognize its weaknesses in the electronics field but nevertheless points out that it does have 3,000 software engineers which can assist in entering the electronics and information-processing fields. Not surprisingly, the emphasis at the moment is on the development of computers, telecommunications equipment and data systems. The company's first personal computer was launched in April 1991 in foreign markets, where it hopes to gain a foothold, and then advance into the domestic market already dominated by established companies such as Toshiba and NEC. The company's investments in these areas over the last four years are viewed as its "ground-breaking" for its electronics business, according to the chief executive of electronics. He also sees developments in new semiconductor technologies as laying the groundwork for obtaining various types of high-speed processing equipment relatively cheaply. The company, moreover, is avoiding the cut-throat competition in such areas as memory semiconductors and focusing instead on markets for customized electronic devices ("boutique" electronics).

5. *Diversification into new materials*

As of 1985-1986, many steel companies, along with firms from chemicals and other sectors, entered the new materials field largely as a means to escape the recession and as a strategy for profit and growth. One of the reasons for the switch to new materials was the need to transfer surplus personnel to new fields as part of the continuing restructuring programmes. The 1987-1988 recovery in domestic demand for existing steel products, however, removed the more immediate need to use new materials as a boost to profitability. The role of the new corporate materials divisions have been played down somewhat of late but they remain active.

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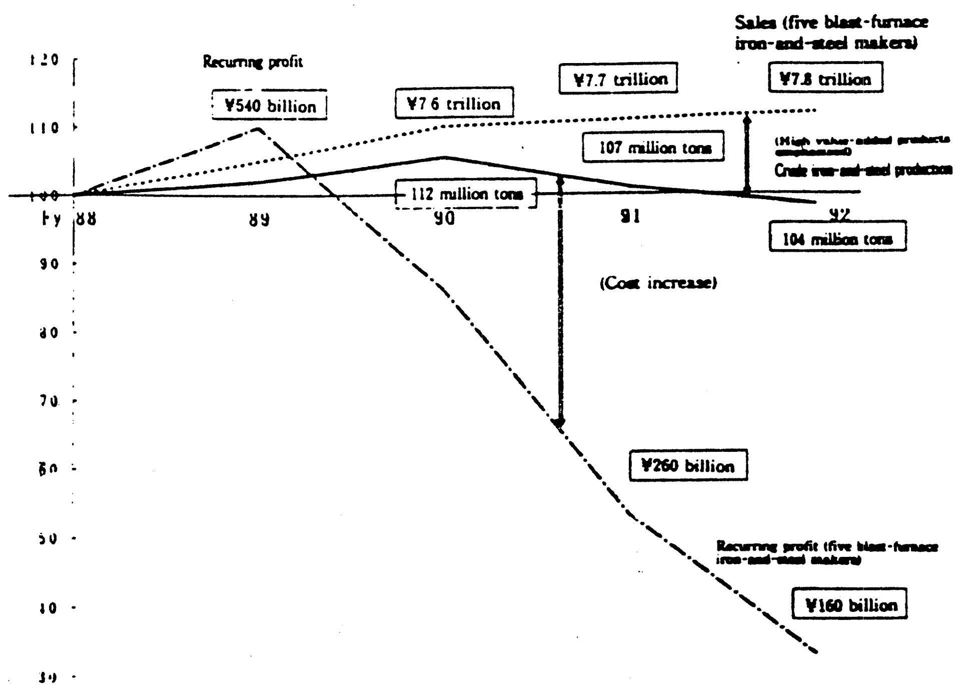
[13] *Financial Times*, 7 June 1991.

Figure 21. Iron and steel industry production and income trends



Source: Industrial Bank of Japan, 1992.

He emphasized that the economic and strategic health of a nation could not be based solely on high-technology solutions and that the nation's future would rest on an industrial base balanced between the smokestack basic materials industries, including traditional metals and alloys, and the new and advanced materials industries. He added that basic materials industries directly represented more than $250 billion in annual revenues for the United States and close to 3.4 million jobs, or roughly 20% of the country's workforce, but he acknowledged that materials science and engineering activities affected more than one third of the gross national product (GNP) of the United States.

Finally, the rejected suggestions that the decline of the basic industries was the logical result of a competitive market-place and that the economic health of the nation was better served by allowing these industries to perish. He insisted that, in the interest of the nation's overall security, these industries should be incorporated into a reindustrialized and revitalized market-place.

Table 2. New business goals of the five major blast-furnace steelmakers

Company	Plan name (goal year)	New business goal profile	
Nippon Steel	All-Company Medium- and Long-Term Business Goals (FY 1995)	FY 1995 business scale of yen 4 trillion	
		Steel Division	60%
		New materials, chemistry, engineering	10%
		Electronics, data communication	20%*
		Social and Lifestyle development	10%*
		Biotechnology too	
		(* New business 30%)	
NKK	New Future Vision (NFV) (FY 2000)	FY 2000 sales of yen 1.6 trillion	
		Steel	50%
		Integrated engineering	25%
		Integrated urban development	12.5%
		Electronics, new materials, biotechnology	12.5%
Nawasaki Steel	Year 2000 Business Vision (FY 2000)	FY 2000 sales of yen 2 trillion	
		Steel	58.5%
		Engineering	9%
		Chemistry	2.5%
		New business	30%
Sumitomo Metal Industries	Long-Term Vision (FY 1995)	FY 1995 sales of yen 1.3 trillion	
		Steel	61.5%
		Engineering	12.3%
		Electronics, data service	10.8%
		New materials, chemistry	8.5%
		Service, other	6.9%
Kobe Steel	New Medium- and Long-Term Management Plan (FY 1995)	FY 1995 sales of yen 1.6 trillion	
		Steel, welding division	32%
		Light, alloys, stretched copper products	24%
		Machinery, engineering	24%
		New business	20%
		(New business: electronics, data communications and other new materials, biotechnology, amenities, and all phases of developer business).	

Source: Industrial Bank of Japan.

Figure 22. Diversification matrix

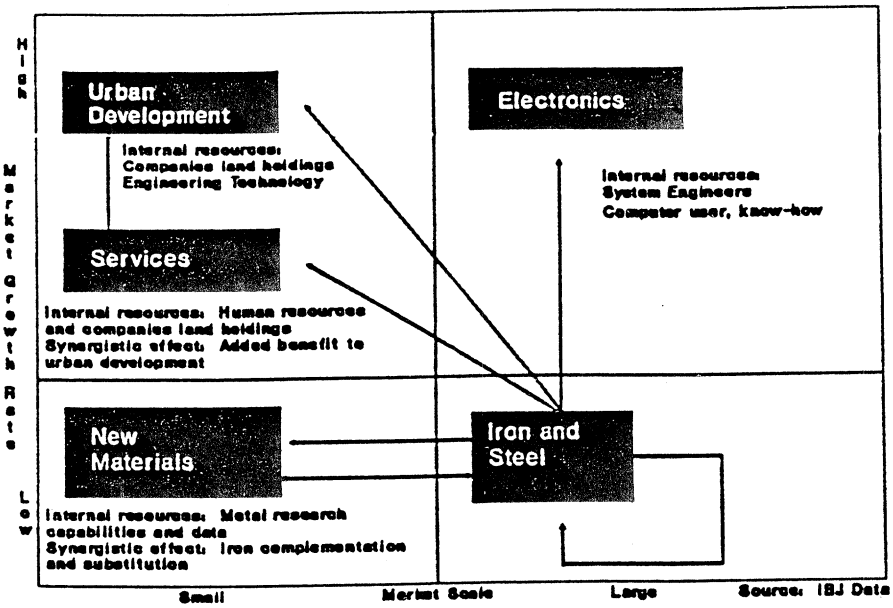
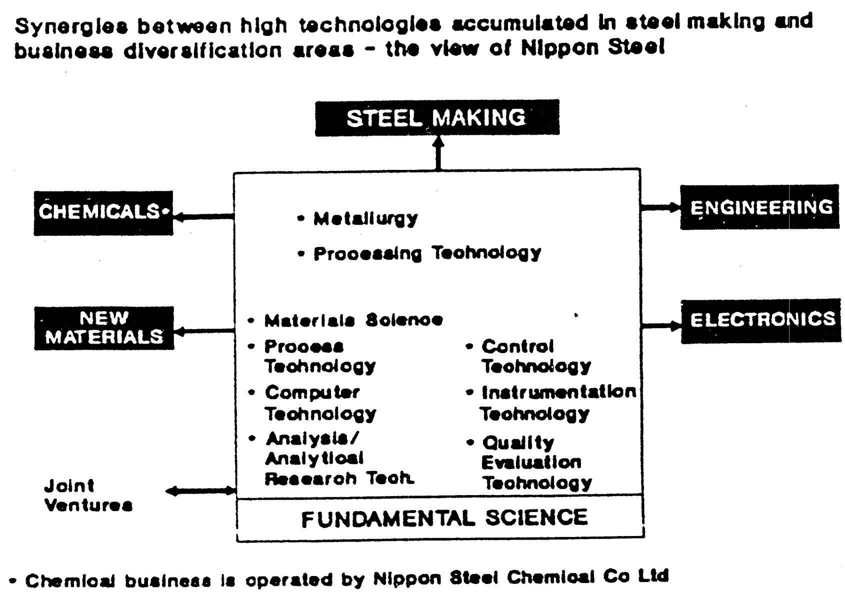
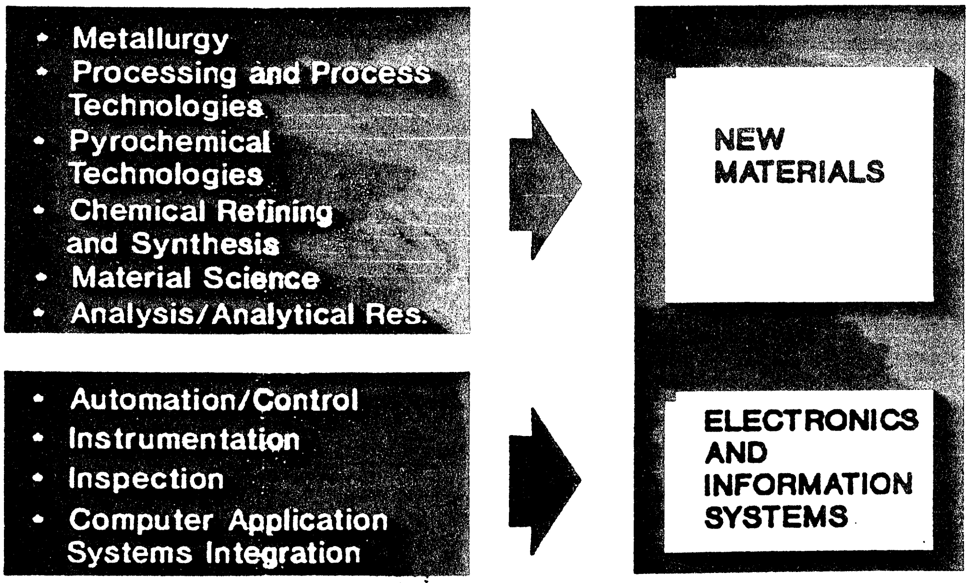


Figure 23. Business diversification linkages



Source: Adapts from information provided by Nippon Steel.

Figure 24. Accumulated technologies applicable to create new business



Source: Nippon Steel.

In order for future changes in basic industries to be understood, two aspects should be borne in mind. Increasingly, technical change and trends in materials-using industries (e.g., automobiles micro-electronics and machinery)impose an ever more stringent and diverse set of requirements on an evolving materials sector. On the other hand, the materials sector itself is permeated with new scientific insights and engineering capabilities which facilitate both the response to user-industry requirements and the autonomous creation of innovations in the materials field. Hence, the restructuring of primary industries in the 1970s, 1980s and 1990s goes far beyond the relative decline of traditional metal and chemicals industries within IACs. It is also closely integrated with the far-reaching transformations under way in materials-using industries.

C. CHEMICALS

For most of the 1980s, heavy petrochemicals and commodity plastics fared very badly; the major chemical companies and the chemical subsidiaries of the oil companies restructured their operations to reduce their exposure to the bulk sector while increasing their presence in specialties. Several companies attempted to reduce their capacity in heavy petrochemicals without endangering their market share. At the same time, research-intensive specialties aimed at high-growth market segments and protected by patents produced remarkable profits for the companies.

The chemicals industries of Europe, Japan and the United States, responding to the crisis in commodity chemicals in the late 1970s and early 1980s, have displayed a similar tendency to divest or downsize traditional commodity plastics, in order to consolidate and diversify into specialties, pharmaceuticals and advanced materials. A massive effort has been under way to move into downstream higher-value-added products and markets, strengthen current business, and expand markets and diversify into new areas and technologies. The most common method whereby companies moved to specialties and diversified into related or new business was by acquisitions, which rose dramatically in the United States in the 1980s. Chemical companies entered advanced materials, such as fibre and metal-matrix composites, engineering plastics, ceramics and electronic materials. They also entered medical technology, biotechnology, pharmaceuticals and specialty chemicals, such as catalysts, coatings, enzymes and electronic chemicals.

There was an invasion of the United States chemicals industry in the 1980s, particularly by European firms and, more recently, Japanese firms, to establish a presence in the United States market and acquire new technology.[14] The Japanese chemicals sector has been driven by the need to access new markets and new technology, through acquisitions, technology purchasing, licensing and joint ventures. Traditional chemicals companies are thus transitioning to large, multinational, diversified materials companies involved in advanced materials, life sciences, biotechnology and electronics.

However, the global restructuring and ongoing transformations of the chemicals industry does not mean that commodity petrochemicals have ceased to be of importance. Basic petrochemical feedstock operations (see figures 27 and 28) continue to provide essential inputs to downstream chemicals activities. At the same time, petrochemical operations continue to shift to energy-rich regions, such as the Middle East, where they enjoy a comparative advantage. Here, large multinational oil companies have a large presence in commodity chemicals through joint ventures with host-country companies or Governments.

In 1987 and especially 1988, a remarkable turnaround occurred in the chemicals industries: a strong upsurge in demand, low feedstock prices and high capacity utilization brought higher prices and profitability. This marked the best market and profitability conditions which the industry had seen in two decades. Interestingly, commodity plastics and heavy petrochemicals also shared in the increase in profitability; in fact, they contributed substantially to the exceptionally high, 22% return on chemical assets of oil companies (up from 13% in 1987). The oil companies did not engage in large-scale running down of their petrochemical capacity because of their access to feedstock and the refining end of their business. Table 5 summarizes the performance of the chemicals sector from 1983 to 1991.

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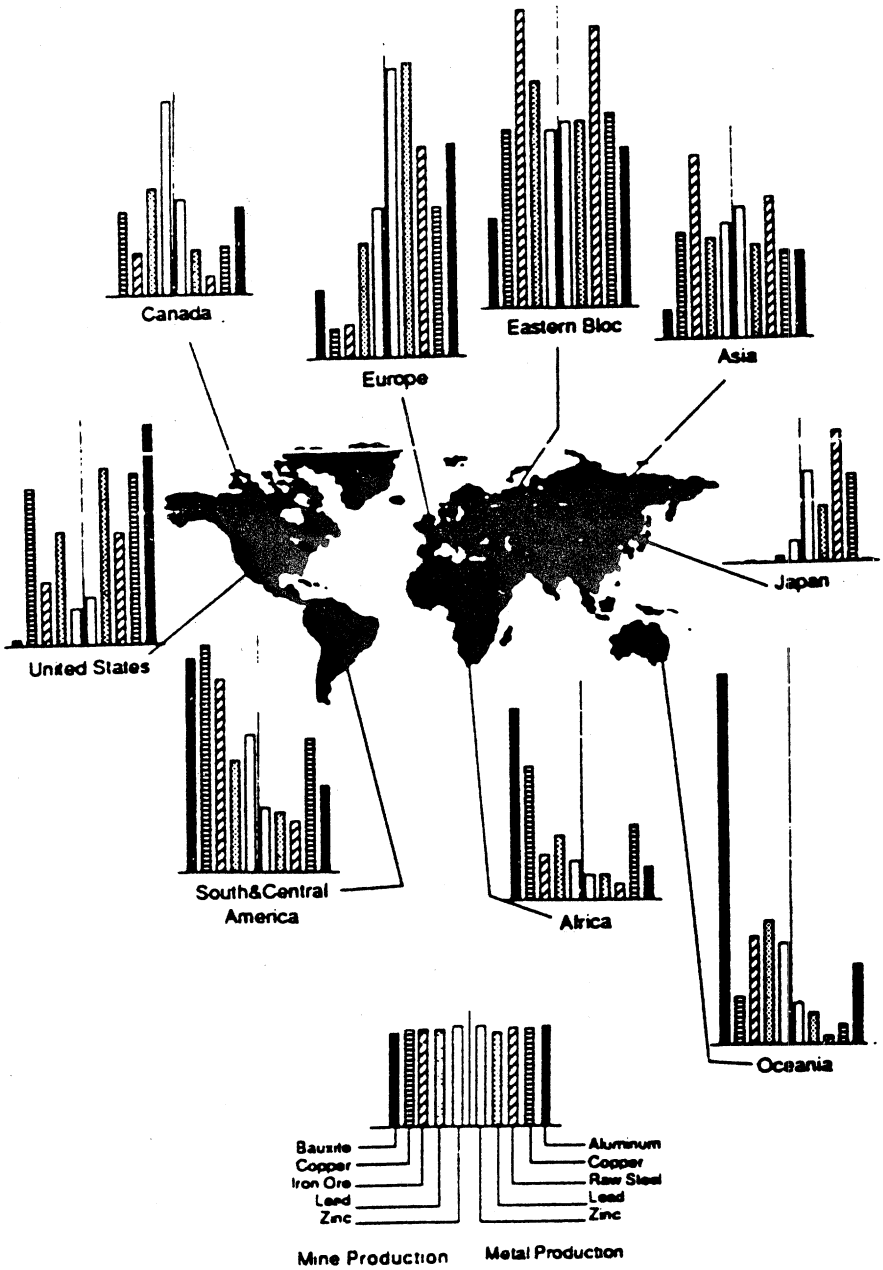
[14] See the Working Papers of the MIT Commission on Industrial Productivity, vol. 1, MIT Press, 1989.

Table 3. Major United States-Japan steel tie-ups

Japanese company	United States company	Date established	Business details
Nippon Steel	Inland Steel	July 1987	Automobile cold-rolled sheet steel production
		September 1989	Automobile surface treatment sheet steel production
NKK	National Steel	August 1984	Capital participation (integration producer)
	National Steel Dofasco, Canada	Autumn 1989	Automobile surface treatment sheet steel production
Kawasaki Steel	Rio Dose (Brazil)	July 1984	Acquired former Kaiser Steel Fontana works (sheet steel production)
	Armco	March 1989	Acquired Armco Middletown and Ashland works (automobile surface treatment sheet steel integrated production)
Sumitomo Metal Industries	LTV	January 1985	Automobile surface treatment sheet steel production
		May 1989	Automobile surface treatment sheet steel production
Kobe Steel	USX	July 1989	Acquired USX Lorain steelwork (bar steel, pipe production)
Nisshin Steel	Wheeling-Pittsburgh	July 1984	Automobile surface treatment sheet steel production

Source: Industrial Bank of Japan.

Figure 25. World distribution of mine output, metal production and consumption



Source: United States National Research Council.

Figure 26. 1989 net import reliance of selected non-fuel mineral materials as a percentage of apparent consumption[a,b,c]

Mineral	Net import reliance (%)	Major Sources (1985-88)
ARSENIC	100	France, Sweden, Mexico, Canada
CESIUM	100	Canada, Fed. Rep. of Germany
COLUMBIUM (niobium)	100	Brazil, Canada, Thailand
MANGANESE	100	Rep. of South Africa, Gabon, France*
MICA (sheet)	100	India, Belgium, France, Japan
RUBIDIUM	100	Canada
STRONTIUM (celestite)	100	Mexico, Spain
THALLIUM	100	Bel.-Lux., U.K., Fed. Rep. of Germany, France
GEM STONES (natural & synthetic)	99	Belgium, Israel, India, Rep. of South Africa
BAUXITE & ALUMINA	97	Australia, Guinea, Jamaica, Suriname
DIAMOND (industrial stones)	95	Ireland, U.K., Rep. of South Africa, Zaire
PLATINUM-GROUP METALS	94	Rep. of South Africa, U.K., U.S.S.R.
FLUORSPAR	91	Mexico, Rep. of South Africa, China, Spain
COBALT	86	Zaire, Zambia, Canada, Norway
TANTALUM	85	Thailand, Brazil, Canada, Australia
CHROMIUM	79	Rep. of South Africa, Turkey, Zimbabwe, Yugoslavia
BARITE	77	China, India, Morocco
TIN	73	Brazil, China, Indonesia, Malaysia
TUNGSTEN	73	China, Bolivia, Fed. Rep. of Germany, Canada
POTASH	72	Canada, Israel, U.S.S.R., German Dem. Rep.
ASBESTOS	65	Canada, Rep. of South Africa
NICKEL	65	Canada, Norway, Australia, Dominican Republic
ZINC	61	Canada, Mexico, Spain, Peru
ANTIMONY	60	China, Rep. of South Africa, Mexico, Hong Kong
SELENIUM	59	Canada, U.K., Japan, Bel.-Lux.
CADMIUM	56	Canada, Australia, Mexico, Fed. Rep. of Germany
IODINE	56	Japan, Chile
STONE (dimension)	48	Italy, Spain, Canada, Taiwan
PUMICE & PUMICITE	43	Greece, Italy
PEAT	41	Canada
GYPSUM	37	Canada, Mexico, Spain
BERYLLIUM	23	Brazil, China, France, Rep. of South Africa
SILICON	23	Brazil, Canada, Norway, Venezuela
QUARTZ CRYSTAL (industrial)	22	Brazil, Namibia
IRON ORE	20	Canada, Brazil, Venezuela, Liberia
MAGNESIUM COMPOUNDS	20	Greece, China, Canada, Ireland
CEMENT	17	Mexico, Canada, Spain, Greece
SODIUM SULFATE	16	Canada, Mexico
NITROGEN	14	Canada, U.S.S.R., Trinidad & Tobago, Mexico
IRON & STEEL	13	EC, Japan, Canada, Rep. of Korea
ZIRCONIUM	13	Australia, Rep. of South Africa, Argentina, Canada
COPPER	9	Canada, Chile, Peru, Zaire
LEAD	8	Canada, Mexico, Australia, Peru
SALT	8	Canada, Mexico, Bahamas, Chile
SULFUR	8	Canada, Mexico

Note: For a number of minerals, import reliance data are withheld or incomplete. However, commodities for which sufficient data are available to indicate a significant degree of import dependency include: andalusite (South Africa), bismuth (Mexico, Belgium, Peru, United Kingdom of Great Britain and Northern Ireland), graphite (Mexico, China, Brazil, Madagascar), ilmenite (Australia, Canada, South Africa), mercury (Spain, China, Turkey, Japan), pyrophyllite, wonder stone (South Africa), rhenium (Chile, Federal Republic of Germany), rutile (Australia, South Africa, Sierra Leone), tellurium (Canada, United Kingdom, Japan, Phillipines), and vanadium (South Africa, South America, European Community, Austria).

a Estimated.
b Net import reliance imports - exports + adjustments for Government and industry stock changes.
c Apparent consumption: United States primary + secondary production + net import reliance.

Table 4. Production and surplus capacity cuts by major industrial sectors

Industry	Execution period	Outline
Coal mining	1987 - 1991	FY 1986 FY 1991 Coking coal 2,910,000 t/yr. --> 0 t/yr. Ordinary coal 14,200,000 t/yr. --> Approx. 10,000,000 t/yr. Total Approx. 17,110,000 t/yr. --> Approx. 10,000,000 t/yr. Production system integration to attain the target shown above (Based on the Coal Mining Council Report of Nov. 1986).
Pulp/paper	May '83-Jun. '87	Linerboard and corrugating medium production facilities Approx. 7,600,000 t/yr. --> Approx. 6,800,000 t/yr. (as on Jul. '86)
	Oct.'83-Sep.'86	Machine-made paper production facilities Approx. 9,600,000 t/yr. --> Approx. 8,400,000 t/yr. (as on Jul. '86) (Based on the structural improvement basic scheme of industrial structure low).
Chemicals	Jun.'83-Mar.'85	Ethylene production facilities Approx. 6,300,000 t/yr. --> Approx. 4,300,000 t/yr. (as on Jul. '86)
	Jun.'83-Jun.'85	Polyolefin production facilities Approx. 4,100,000 t/yr. --> Approx. 3,300,000 t/yr. (as on Jul. '86)
	Jun.'83-Mar.'85	Vinyl chloride production facilities Approx. 2,200,000 t/yr. --> Approx. 1,700,000 t/yr. (as on Jul. '86) (Based on the structural improvement basic scheme of industrial structure low).
	FY 1983	Atmospheric distillation facilities Approx. 6,000,000 B/D. --> Approx. 5,000,000 B/D.
Petroleum	FY 1986-FY 1988	Atomospheric distillation facilities Approx. 5,000,000 B/D. --> Approx. 4,300,000 - 4,000,000 B/D. (Based on the Petroleum council recommendation of Sep. 1985).
Cement	May '84-Mar. '86	Cement production facilities 129,000,000 t/yr. --> 89,000,000 t/yr. (Based on the structural improvement basic scheme of industrial structure law).
Iron, steel	Around FY 1988-FY 1990	Production facility integration and personnel cuts to reduce total crude steel output to 90 million tons per year, as compared to the 1986 capacity of 1,500 million tons per year. <Plans of major blast furnace steelmakers> Blast furnaces 34 units --> 27 units Suspension and integration of plate plants, rolling mills and steel pipe production facilities. (Rationalization scheme of all the major blast furnace companies).
Aluminum smelting	May '83-Jun.'87	Aluminum smelting facilities 1,640,000 t/yr. --> 50,000 t/yr. (Jul. '87) (Based on the structural improvement basic scheme of industrial structure law, May '83 - Jun. '87).

Source: MITI.

As table 5 indicates, chemical and oil companies registered a strong performance in 1988 and 1989. The deterioration of trading conditions in 1990 drove profits down towards more normal levels. However, the recessionary forces proved more intractable than at first thought, as companies were exposed to the heavy-petrochemicals sector and experienced sharp reductions in profitability by 1991. Average returns on assets in a sample of 10 chemical companies and 7 oil companies fell dramatically to 3.2% in 1991 from 1990 figures of over 12% and 5.3%. Moreover, contrary to earlier experience, the performance of the oil companies' chemical operations was particularly bad, due perhaps to the concentration of their chemical operations in the United States market. The sharp decline in oil companies' chemical operations, resulted in a drop in the share of total earnings from chemicals to 3.9%, compared to 7.1% in 1990 and over one fifth for the period 1987-1989.

Companies which embarked on successful programmes of moving away from heavy petrochemicals and onto high-value-added and research-intensive products experienced less of a decline in profitability than those which remained exposed to the commodity and heavy-petrochemicals sector. Moreover, companies generally experienced better conditions in the higher-growth markets of the Pacific rim than in the United States or Europe.

1. *The European chemicals industry and environmental regulation*

The European chemicals industry is experiencing probably its worst period since the Second World War. The depth and persistence of the recession is posing the greatest difficulty in the short to medium term, and there is disagreement as to the timing of the upswing in the business cycle and its differential impact on the various branches of petrochemicals and chemical products. The major European chemical companies, Hoechst, BASF and Bayer, have belatedly embarked on major restructuring and cost-cutting rationalization programmes. Evolving strategies over the long term are, however, unavoidably influenced by the rising costs of meeting strict environmental regulation laws while attempting to remain competitive within the Single European Market from January 1993.

The major German chemicals groups are coordinating a programme of opposition to the proposed government legislation on the environment which includes:

(a) A change in 1993 of 200 deutsche marks (DM) on each tonne of hazardous waste produced;

(b) A levy on carbon-dioxide emissions which may cost the chemicals industry approximately DM 500 million per annum;

(c) A solid-waste charge on non-hazardous by-products used in land fills, which may add DM 80 million a year to BASF's costs and DM 290 million to Bayer's costs.

Table 5. The chemicals sector, 1983-1991
(Average return on chemical assets, percentage)

	1983	1984	1985	1986	1987	1988	1989	1990	1991
Chemical companies of which:	3.6	5.4	2.6	5.8	5.9	7.7	8.0	5.0	3.4
West Europe based	3.4	5.1	5.1	5.4	5.6	6.4	7.6	4.8	3.9
US based	3.9	5.7	-0.6	6.3	6.3	9.7	8.7	5.4	2.6
Oil companies	-0.1	4.8	3.9	10.1	12.8	22.0	18.7	5.8	3.2
Both	2.0	5.1	3.2	7.7	8.9	13.6	12.4	5.3	3.2
Share of oil companies' earnings deriving from chemical sector	1.0	5.3	3.8	12.1	19.2	24.1	23.2	7.1	3.9

Source: Petroleum Economist, July 1992.

Given the deteriorating market conditions and the sharp drop in profitability by the three groups, such measures are viewed with trepidation, since they add to the considerable environmental clean-up expenses which the German chemicals groups have been forced to bear in recent years. BASF has reduced effluent load into the Rhine by 95% since 1973, and air emissions by 80-85% over the same period. Between 1988 and 1992 the company spent DM 500 million on pollution control, while it plans to spend DM 900 million between 1990 and 1994 and as much as DM 1.6 billion between 1992 and 1996. Environmentally related initial capital expenditure is accompanied by high environmental operating costs, with each mark of capital expenditure adding 40 pfenings DM 0.40 to running costs, according to BASF (see table 6 for the 1991 figures and comparisons to other European groups). Bayer estimates that a total of DM 1.9 billion must be spent by the group on environmental capital projects over the next five years. Furthermore, Bayer claims that chemical-plant operations in Germany involve environmental costs which have doubled over the last six years, and now comprise 8% of sales. Already Bayer, BASF and Hoechst have begun investing outside Germany, and this is likely to accelerate in the future if an additional burden is imposed with the implementation of the proposed environmental legislation.

2. *Overcapacity in European petrochemicals*

In a repeat of conditions prevailing in the early 1980s, the petroleum sector is facing severe difficulties brought on by the simultaneous onset of recession and overcapacity. The long-term viability and structural problems facing the industry were briefly masked by the extraordinary surge in demand experienced in the late 1980s. At the same time, profitability reached dizzying heights, with companies reducing bottlenecks and expanding capacity such that European ethylene output rose to 18 million tonnes in 1990 from 16 million in 1988. Forgetting the lessons of the early 1980s, the industry reacted to the extremely high profit margins (which could have paid off a new plant within a year!) by expanding production. Four new ethylene plants are coming on stream and will begin production within two years. Overall, the industry is unlikely to recover the $3 billion construction costs of the new plants by the year 2000. Ethylene supply by 1994 in Europe will be 20 million tonnes per annum, while demand will only be 15-16 million tonnes (see figure 29 for global ethylene capacity, demand and utilization). Today, margins and prices have fallen significantly, with a negative 2% net on investment. There is therefore a need for the industry to face the structural problems with a comprehensive, long-term approach. European petrochemicals are at a cost disadvantage *vis-à-vis* United States and Middle East producers, a situation aggravated by the fall of the dollar, thus eliminating the prospect of exports as a solution to the present crisis. Besides, even if demand picks up, this will lead to a price rise and to import penetration from United States producers also suffering from surplus capacity.

The pressure for deep restructuring and rationalization measures is therefore becoming very strong, but it is encountering serious economic, inertial and political obstacles. The most inefficient plants were already closed in the 1980s, although cost differences among Europe's 53 ethylene plants are still considerable. The costs of plant closures, financial, environmental and social, are very large, especially if they imply relocation of downstream user industries (polyethylene, polypropylene, polystyrene and PVC). Many industry analysts agree that the European petrochemicals sector cannot simply remain inactive waiting for demand to pick up. This may not take place until the late 1990s, and even if it does, prices and margins may not improve. This is due to fundamental changes in the global supply-and-demand situation, resulting from the vast additional capacity now coming on stream in the Far East. European petrochemical producers will lose their markets in Asia, while low-cost producers in the Middle East may also be forced to divert output to Europe as they come under competition from Asian producers. The latter are also likely to penetrate European markets at low prices in an effort to generate hard currency.

The problems facing European petrochemical producers are therefore severe and of a structural nature, calling into question the very viability of a European petrochemicals sector in the long run, even if the sector successfully implements fundamental rationalization and cost-cutting measures.

3. *Company responses*

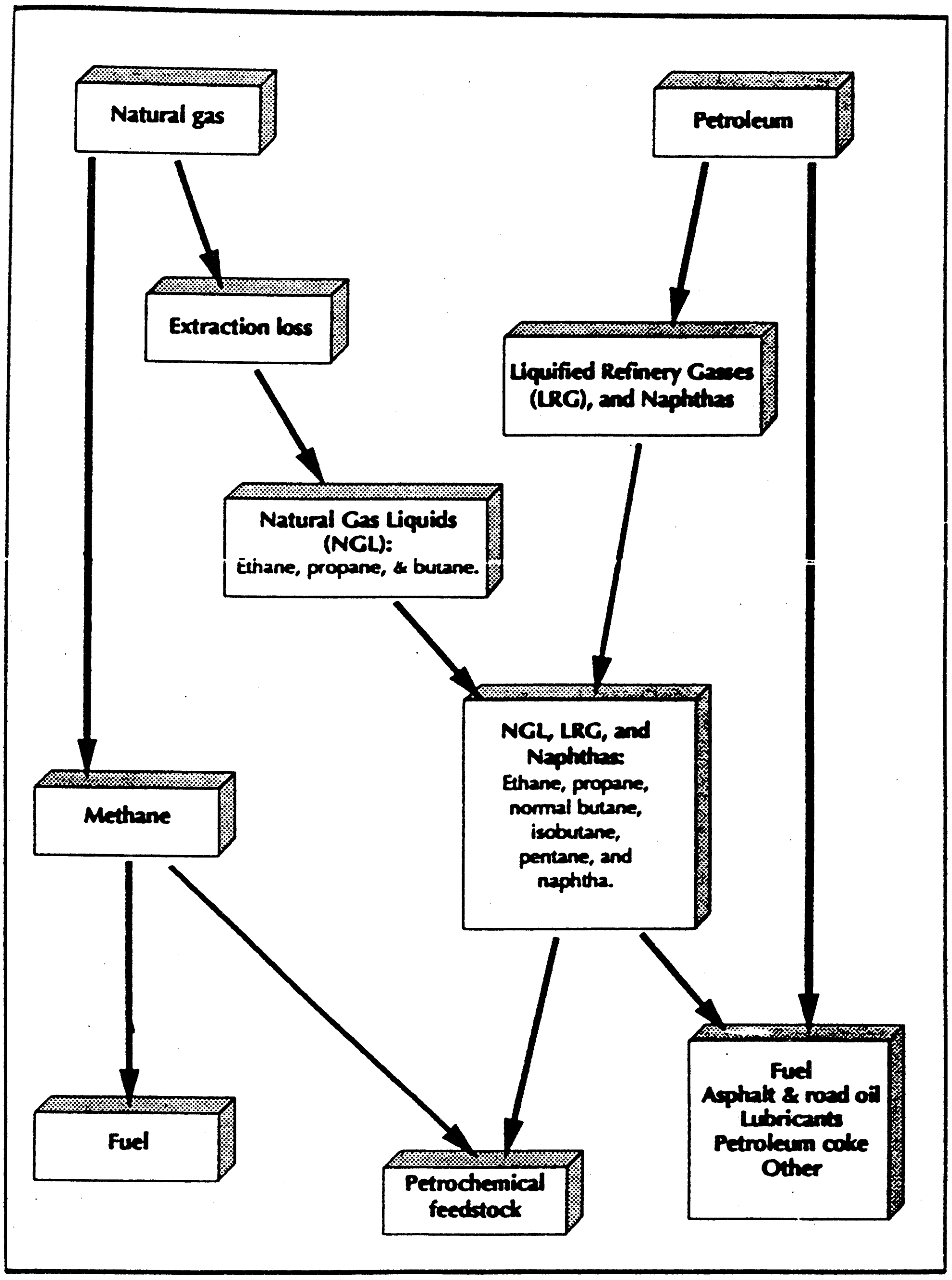
Chemical companies are adopting a variety of strategies to deal with unfavourable demand prospects and the pressing need for industry-wide rationalization, including continuing divestment of assets and exits from specific lines, joint ventures, mergers, asset swaps and agreements over plant sharings. In Europe, for example, it appears that producers of polyethylene and polypropylene may be attempting to join forces, thus facilitating the elimination of surplus capacity. Joint ventures are becoming a popular strategy by which companies respond to demand shortfalls. In May 1992, Enichem and British Petroleum (BP) agreed to cooperate in polyethylene R&D, which will enable Enichem to use BP's fluid-bed process for its new linear-density and high-density polyethylene plant at Brindisi in 1994. The companies may also form linkages in the styrenic plastics business, thus becoming the largest supplier in Western Europe. Earlier in the year, ICI and DuPont agreed to swap their nylon and acrylics business (subject to EC approval) thus enabling ICI to become the largest producer of acrylics in the world, while DuPont would become the largest producer of nylon in Europe.

Following a decade of massive restructuring several major companies are currently still disposing of assets and fine-tuning their product portfolios. In August 1992, Monsanto sold its Fisher Controls valve and systems subsidiary for nearly $1.3 billion to Emerson Electric. A number of its prized products (e.g., Roundup, the world's best-selling agrochemical, and Nutrasweet) are facing competition from generic producers since their patents have either recently expired or are about to expire. Moreover, in an effort to overcome the cyclical problems of the chemical industry, Monsanto has invested over $1 billion in biotechnologies since 1981, but the results as yet have been unsuccessful. Also in August 1992, BP Chemicals continued the restructuring of petrochemicals by the proposed sale of its low-density polyethylene plant at Antwerp to Neste Chemicals of Finland. BP Chemicals aims to concentrate its polyolefins operations on areas in which it possesses competitive strengths. The company is building a 333,000 tonne-per-year (tpy) plant at Grangemouth and wants to concentrate on ethylene derivative production using cheap gas rather than naphtha feedstocks. On the other hand, Neste is also buying BP America's performance polymer business in New Jersey. Internal BP documents speak of the European petrochemicals industry suffering from chronic overcapacity, urging immediate action. In line with this, it is reported that BP is currently considering closing at least one plant in its Baglan Bay complex in South Wales, probably a 120,000-tpy ethylene unit supplying BP's low density polyethylene plant at Antwerp which is being sold to Neste.

Cost-cutting and asset divestment by companies such as BP, ICI and Hoechst (e.g., closures of dyestuff plants in Germany) are also accompanied by more clearly focused strategies and investment in areas of existing strengths and established presence, as in, for example, the polymers sector. Hoechst and DSM are shifting funds into polyethylene, Hoechst into polypropylene, and BASF into polyurethane. Exxon is constructing polyethylene and polypropylene facilities in France. Amoco is expanding its capacity in isophthalic acid and terephthalic acid in Belgium.

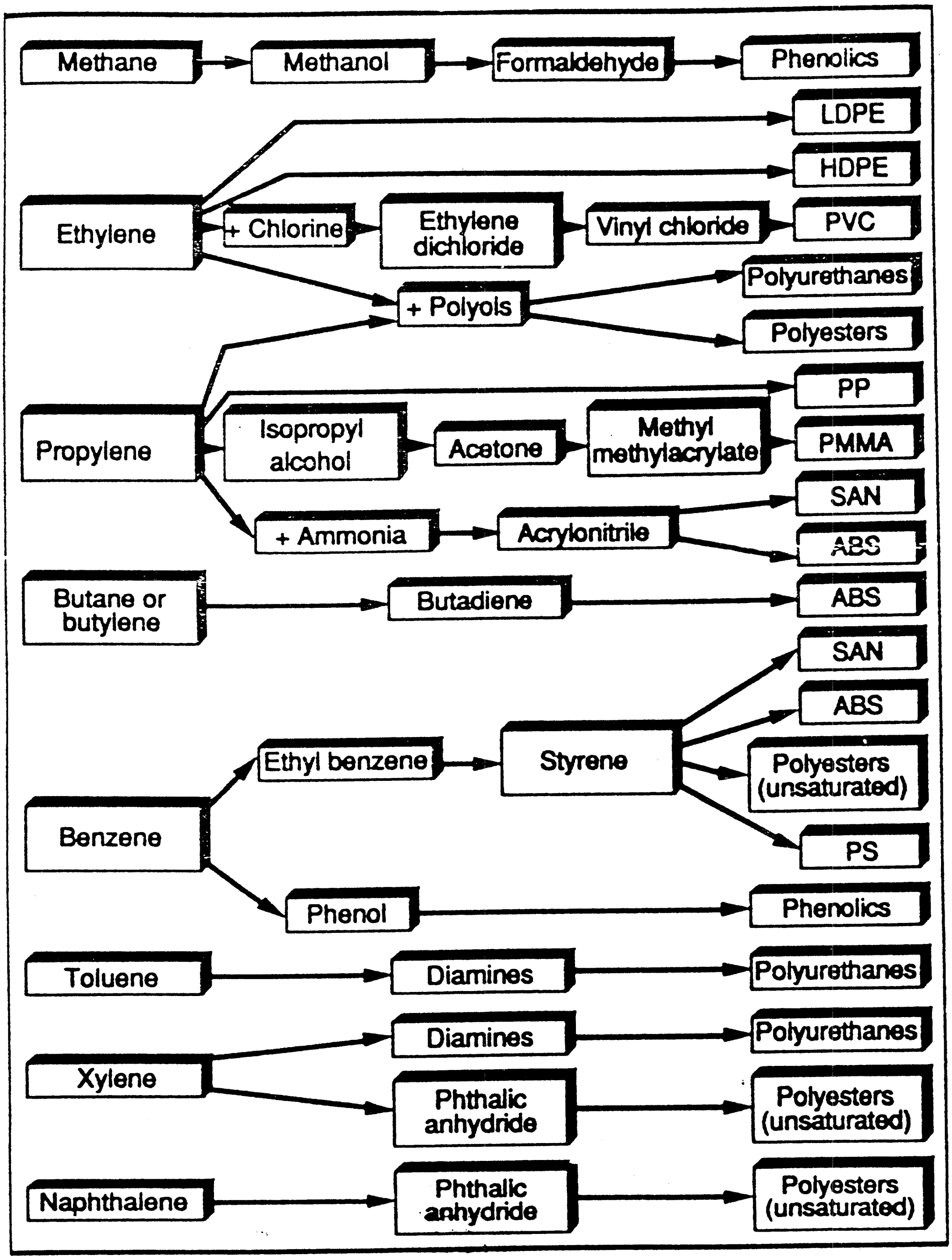
Recession, overcapacity and intensification of global competition have all led to radical restructuring plans announced in August 1992 by ICI in the United Kingdom and DuPont, the biggest United States chemicals group. ICI has attempted to reinvent itself by splitting off its pharmaceuticals business and engaging in a programme of deep cost-cutting. The aim of this "demerger" is to have separate technologies catering to discrete and bounded product lines, an idea that may prove to be wholly inappropriate in current circumstances, and not shared by ICI's German rivals Hoechst, Bayer, and BASF. The latter apply a broad range of scientific expertise, generic technologies, management expertise and skills across the product range and in chemical production processes enjoying the economies of scale.

Figure 27. Materials flow from well to feedstock



Source: U.S. Bureau of Mines, The New Materials Society, 1990.

Figure 28. Materials flow from feedstock to resin



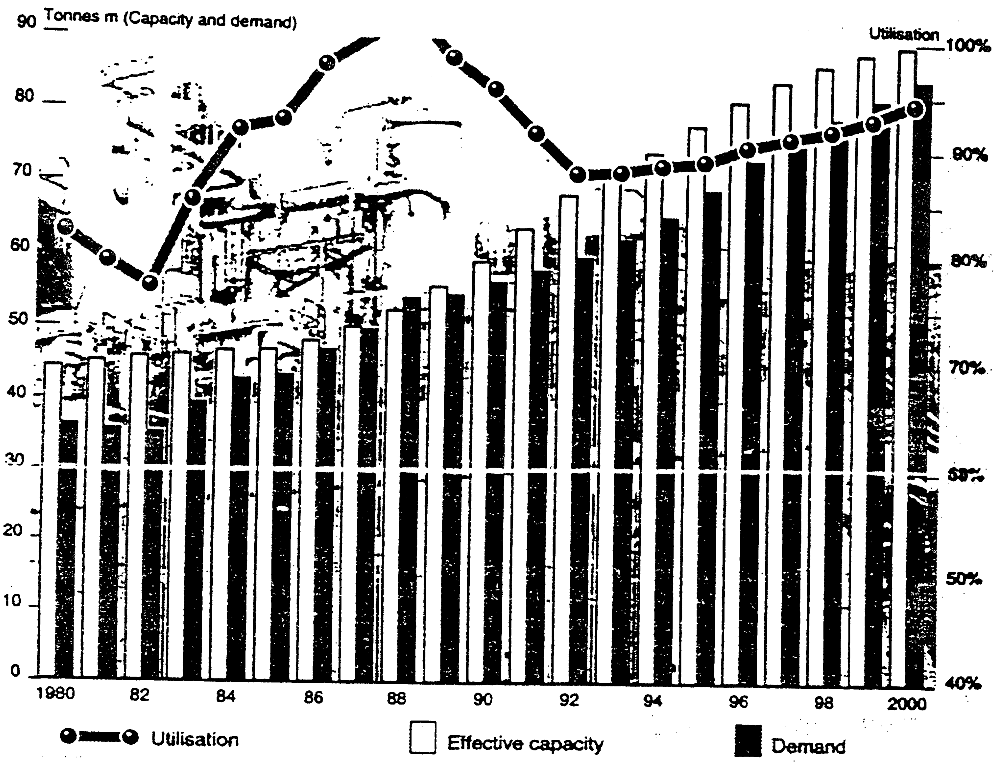
Source: U.S. Bureau of Mines, The New Materials Society, 1990.

Table 6. Clean-up spending by chemical groups

1991	Capital expenditure on environment (millions)	Environmental running costs (millions)	Total environmental costs as percentage of turnover
Bayer (Germany)	DM 225	DM 1 400	9.0%
BASF (Germany)	DM 368	DM 1 065	7.0%
Hoechst (Germany)	DM 343	DM 1 558	11.0%
ICI (World-wide)	120	230	2.8%
Rhone-Poulenc (France)	FF 864	FF 589	1.7%

Source: Financial Times, 1 July 1992.

Figure 29. World ethylene capacity, demand and utilization



Source: BP Chemicals.

DuPont's response to the difficulties faced in the United States chemicals market has been rather different from that of ICI. The company's strategy involves dramatic cost-cutting, geographic expansion and concentration on core businesses. Plans are afoot to cut $1 billion in overhead from chemicals businesses by 1994, and a further cut of $2 billion in operating costs throughout the company. Non-core assets are to be liquidated, an undertaking that involves the sale of its connector business, which makes components for the computer industry, the sale of half of its coal business for $1 billion and possibly all or part of its imaging division, which makes film, printing and reproduction equipment.

At the same time, the company is concentrating on core activities, with, for example, an investment of $1.5 billion over the next 10 years to modernize its United States nylon (i.e., the engineering polymer polyamide) production facilities and a $300 million investment to modernize its United States polyester plants in response to Nan Ya of Taiwan Province of China, which is building a polyester plant in South Carolina. To enhance its international presence, DuPont is considering one or more major takeovers in Europe, where it aims to treble its non-energy revenues by the end of the decade. It is investing $240 million in a new pigment plant in Taiwan Province of China and has swapped its remaining acrylics business for the European nylon holdings of ICI. In the 1980s, DuPont halved—to about one fifth—the proportion of its non-energy income of $22.8 billion, which it derives from low-margin commodity chemicals. The proportion of income derived from bulk chemicals is much larger for Dow Chemical and Union Carbide.

In all, the company is reorienting itself towards greater cost-efficiency, refocusing the corporate culture, concentrating on core activities in high-value-added specialties, getting much closer to the customer and becoming a market-driven corporation. The restructuring strategies of the chemicals giants are, of course, closely scrutinized by the much smaller but ambitious Japanese chemicals groups as they reconsider their strategies in 1992.

D. Chemical and petrochemical industries in Japan and South-East Asia

1. *Petrochemical supply and demand in Asia*

As noted in annexes I, II and III, major new ethylene plants are coming onstream in the 1990s, leading to a deterioration in the supply position relative to demand. In particular, the East Asian petrochemicals market is likely to be seriously affected by the construction of six new ethylene plants in the Republic of Korea during mid-1991 to 1992, mainly financed by the *chaebol* (large conglomerates). Preparations are under way for the full operation of these plants, thus leading to oversupply and an exacerbation of the competitive environment in East Asian petrochemicals markets in the near future (table 7).

Ethylene capacity in the Republic of Korea is rising from 500,000 tonnes per year in 1988 to over 3.2 million tonnes per year by 1993. China, Thailand, Indonesia, Taiwan Province of China and Malaysia are adding a total of 2.45 million tonnes of new ethylene capacity by 1995. China alone is doubling capacity from 1.8 million tonnes in 1990 to 3.7 million tonnes by 1995.

Table 7. Capacity additions in the Far East
(Thousands of tonnes per year)

	1988-1990	1991-1992	1993-1995
Ethylene	3 085	3 055	5 210
Polythene	1 665	1 090	1 225
Polypropylene	995	940	710
Polystyrene	422	260	260
PVC	240	460	490

Source: Financial Times, 20 August 1992.

2. *Chemicals in Japan*

The recession of 1991-1992 in Japan and the consequent decline in industrial activity, which spurs the demand for petrochemical products, show no evidence of coming to an end. Both domestic industrial output and personal consumption are likely to continue to exercise downward pressure on the demand for petrochemicals and plastics. This is not likely to be alleviated or resolved by a recovery in overseas demand. Japanese petrochemical producers are therefore operating under conditions of declining growth in demand at a time when several new production facilities are coming on stream, many of them conceived in the high-growth period of the late 1980s. For example, Mitsubishi Petrochemicals' new Kashima ethylene plant was scheduled to begin operations in 1992 together with new HDPE and linear low-density polyethylene (L-LDPE) facilities. And following its first ethylene programme, the Goi programme, Maruzen Petrochemicals is expected to commence planning for its second and third ethylene programmes. Such investment programmes aimed at building new facilities and enlarging existing ones are deemed crucial by firms in order to meet projected medium- and long-term demand and to modernize facilities in order to compete effectively in the international arena.

However, investment plans for expansion need reevaluation in the light of the harsh economic environment currently prevailing, with low growth in demand and rising costs (depreciation, personnel, interest payments, transport and warehouse) leading to a deteriorating business performance in 1991 and throughout 1992. At the same time, several companies are facing redemption of a large number of corporate bonds bearing equity rights. In recent years, aggressive investment programmes have been financed by low-interest instruments such as convertible bonds and warrant bonds, the redemption of which is likely to peak in 1992-1993 (see figure 30). Given the current situation with regard to prices of shares and cost of borrowing in the Japanese financial and money markets, petrochemical companies will need to finance redemptions from drawing down their liquid reserves, refinancing through new bonds (straight and convertible) and borrowing from financial institutions at higher interest rates.

(a) Capital expenditure and R&D strategies: 1980s-1990s

During the 1980s, R&D investment in the Japanese chemical industry grew on average by 10% per annum. Several features of this merit separate mention. By the mid-1980s and thereafter, the proportion of R&D expenditures devoted to basic research had risen to over 10% of the total, in line with the view that the basic sciences and fundamental research had increased in importance for successful innovation in chemicals. For several years now, the industry has been making sustained efforts to improve its basic and applied R&D capabilities, enhance the scale and technological efficiency of production methods as well as the knowledge-intensity of its products.

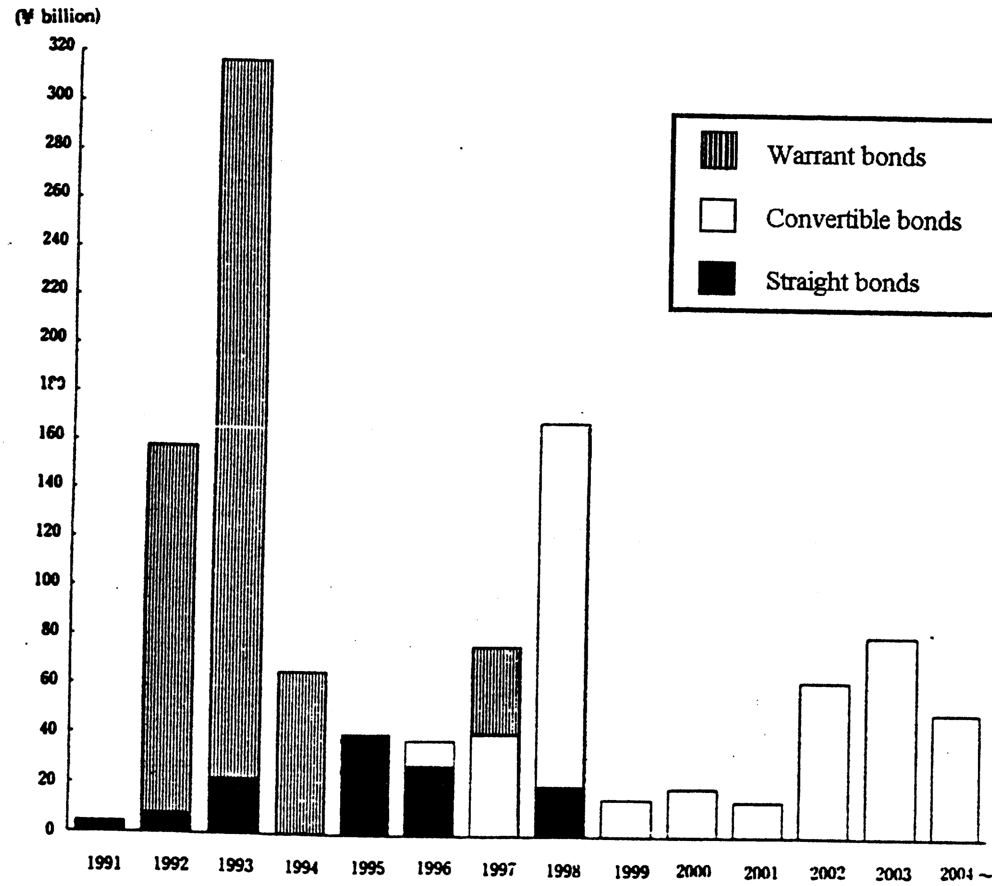
Following the recession of 1985-1986, the chemicals industry achieved remarkable prosperity in the domestically engineered boom of the late 1980s. In several fields the industry aggressively invested a strategy greatly facilitated by the availability of low-interest loans and very high earnings and profitability levels. Chemical companies targeted the fine and specialty chemicals business (e.g., pharmaceuticals and agricultural chemicals) in line with the strong emphasis on restructuring towards high-value-added, high-growth market segments. Engineering plastics is another area which has attracted considerable attention, due to their multi-functionality.

The emphasis on knowledge-intensive chemical specialties and diversification into new materials is reflected in the ambitious long-term strategies unveiled recently by the major Japanese chemicals producers (summarized in table 8) and born in the high growth era of the late 1980s. However, the recession of 1991-1992, the consequent curtailment of investment funds and the deteriorating market prospects are forcing the chemicals industry to carefully re-evaluate its priorities and its investment commitments to new businesses.

The fine and specialty chemicals segment of the industry requires the commitment of huge amounts of R&D funds on a long-term basis; it is risky and its returns come neither easily nor quickly. Similarly, the development of engineering polymers requires the commitment of large R&D expenditures for comparatively small user-market sizes, with even general-use polymers such as PP and ABS imposing a massive cost burden in order to upgrade production capabilities to meet more demanding user needs. It is therefore not surprising that the difficulties recently experienced by companies, a result of the deterioration in economic conditions during 1991 and 1992, are leading to calls for a re-examination of some of the more ambitious plans and diversification strategies.

In this connection, both the chemical companies themselves and government officials are carefully studying the restructuring under way in the United States and European chemical industries. Thus, while the restructuring in the early 1980s took the form of a shift away from bulk chemicals and into research-intensive specialties, the current rationalization measures of the major western chemical companies involve a re-examination of the specialty and engineering polymer businesses, entailing withdrawals, asset swapping and streamlining of operations around core strengths. However, there are certain features of the Japanese industry that pre-empt a simple replication of the western response to the problems afflicting the chemicals industry.

Figure 30. Major petrochemical companies' redeemable debentures outstanding



Sources: Securities reports issued by the individual companies.

Note: Figures are totals for seven petrochemical companies: Mitsubishi Kasei Corp.; Sumitoms Chemical Co., Ltd.; and Mitsui Petrochemical Industries, Ltd.

Table 8. Outline of medium- and long-range plans and fine chemical operations of major Japanese petrochemical firms

		Outline of medium and long-range business plans	Sales & recurring earnings are expressed in 100 millions of yen. The fine chemical rate-the rate of implementation of fine chemical operations to the total-is expressed as a percentage. The fine chemical rate fig.s in parentheses include new materials.				Outline of fine chemical operations
			Year	Sales	Recurring profit	Fine chemical rate	
Specialized Petrochemical Manufacturers	Mitsubishi Petro-chemical Co. Ltd.	Goals include becoming a "creative chemical company" (CCC) and reducing petrochemicals to under 75% and raising fine chemicals to over 25 % of operations by the end of 1990.	1989	3.800	540	15.3(15.3)	(1) Specialty chemicals, including "high performance" resins for pharmaceuticals and industry (2) Biochemicals, biotechnology, pharmaceuticals and agricultural chemicals, including pesticides and technical pharmaceutical products
			1990	4.000	550		
			2001	10.000	-		
	Mitsu Petro-chemical Industries Ltd.	"Long-range business vision" consists of the following: investment of ¥180 billion through 1993; raising capital ratio to 50 percent; and lifting specialty chemicals and other diversified products to 50 percent of total business.	1989	2.930	350	19.4(19.4)	(1) "High-function" materials, including optical disks and VLSI mask pellicles (2) Biotechnology, including shikonin-Kanebo bio-lipstick and cosmetic soap
			1990	3.100	360		
			2000	5.000	500		
General Petrochemical Manufacturers	Mitsubishi Kasei Corp.	Long -range business plan: Formulated plan for 21st century in autumn 1990. 1995 targets: Revenues of ¥1 trillion, recurring earnings of ¥100 billion, and raising "high-function products to 50 percent of total business. 2001 targets: Revenues of ¥1.2 trillion, earning 30 % of revenues overseas (currently 12 %), achieving a 50% ratio of "high-function" products.	1989	7.200	400	5.7(30.8)	(1) Biotech, pharmaceuticals, and agricultural chemicals, including medication for senile dementia, liver medication, and anti-thrombus medication (2) Electronic and other goods for information machines, including PS plates, tonner, photographic sensitizers and floppy disks (3) New materials including pitch-based carbon fiber and alumina fiber
			1991	7.500	410		
			1995	10.000	1.000		
	Sumitomo Chemical Co. Ltd.	"Challenge 21" plan calls for becoming a world-class" excellent company." Group revenues of ¥2.1 trillion in 21st century. Raising ratio of specialty chemicals to total business from current 40 percent to 60 percent in 21st century.	1989	6.017	434	24.5(28.0)	(1) Electronic materials including photoresists and chemicals for semiconductor manufacture (2) Composite and specialty "high-function" materials, including carbon fiber, alumina fiber, and high-performance resins (3) Biotechnology, pharmaceuticals, agricultural chemicals , including seed and plant improvement and alpha interferon
			1990	6.700	450		
			2001	12.000	1.200		
	Mitsui Toatsu Chemicals Ltd.	Long-term business plan: Formulated plan for 21st century in autumn 1990.	1989	3.948	325	11.0(35.0)	(1) Electronic materials, including gasses for semiconductor production and printed circuit boards (2) Biochemistry-related products, including amino acids and seed and plant improvement (3) High-function resins, including phenol, super engineering plastics and separation membranes
			1990	4.200	340		
			1992	4.600	450		
	Showa Denko K.K.	"Plan M" calls for corporate strengthening. By 1994, cumulative plant-and-equipment investment of ¥250 billion, R&D of ¥140 billion.	1989	5.200	335	4.1(40.7)	(1) Electronic materials including conductive resins (2) Ceramic-related products including silicon carbide and zirconia (3) New metals, including metallic alloy for hydrogen storage, rare metals and high-purity iron (4) Biotech., pharmaceuticals including amino acids
			1990	5.300	340		
			1994	7.000	500		
	Ube Industries Ltd.		1989	4.029	319	14.2(16.3)	(1) "High-function" materials , including compound steel sheet and polyimide hollow gas separation membrane (2) Electronic materials, including inductive elements (3) Ceramics-related products including super-high strength fiber (4) Biotech., agricultural chemicals including vitamin B1 intermediates
			1990	4.270	280		
			1995	6.400	450		

Source: Industrial Bank of Japan (IBJ).

Firstly, the very nature of the Japanese corporate system and culture precludes the radical restructuring measures taken in the West (e.g., ICI or BP in the United Kingdom), even if they are assumed to be desirable. Secondly, Japanese managers take a long-term view instead of panic-induced measures at the first signs of deterioration in the short-term profit position, and they have a very clear understanding of the role of science and technology as the foundation of long-term growth. In this respect, corporate management is keenly aware of the fact that new materials, biotechnologies and micro-electronics will be the drivers of Japanese industry into the next century. Chemicals are already interfacing with all the major key technologies of the future, providing critical inputs for micro-electronic and opto-electronic devices while entering into high-performance polymers, polymer-matrix composites, fine ceramics, new metallic substances and pharmaceutical and agricultural chemicals through biotechnology or protein engineering. Within Japan there is wide acceptance of the view that the "Age of New Chemistry" is approaching, which is expected to provide a core technology (while merging with other scientific and engineering fields) for frontier technological innovation in industry. Chemistry is seen as a key critical technology for the 21st century which will enable the development of other key technologies. A major task, therefore, for the chemical industry in Japan is to catch up with and incorporate developments brought in by the Age of the New Chemistry, which would require the commitment of vast sums of capital to basic research, long gestation periods and superior research personnel. It is unthinkable that these long-term perspectives and strategic orientations embraced by Japanese industry would be abandoned by Japanese chemicals corporations on the basis of short-term profitability considerations, an activity that can be performed with astonishing ease although, as western chemical producers have recently shown, it is an act of astonishing short-sightedness.

Thirdly, the need remains for a re-examination of the wisdom and degree of involvement in certain fine and new materials fields, together with streamlining of operations and fortifying of corporate strengths in core businesses. This is likely to be heavily influenced by the enormous fiscal stimulus announced in August 1992 for the Japanese economy, entailing the largest boost ever contrived; and it seems likely to repeat the domestically engineered expansion in demand which followed the 1985 recession, leading to rapid growth in several basic industries, including steel and chemicals. The measures are expected to yield significant and tangible results in domestic economic activity within the next year.

It should be clear, therefore, that the long-term strategic orientations of Japanese chemicals corporations are likely to remain in force, albeit with some modifications arising from the difficulties of the last 2-3 years. Three major issues currently confront the industry: (1) globalization; (2) improvement of fine chemicals as well as pure and applied R&D skills and capabilities; and (3) improvement of the competitive position of the commodity business through the expansion of general-purpose petrochemical facilities and the streamlining of operations.

3. *The Republic of Korea*

(a) Oil refining

The five major oil refiners in the Republic of Korea—Yukong, Honam Oil Refining, Ssangyoung Oil, Kyung In Energy and Kukedong—are aiming to become major exporters of refined oil products, even though the country does not possess any indigenous source of petroleum. Companies from the Republic of Korea are emerging as important players in the international oil market and have been actively bidding for oil exploration rights in eastern Russia and the Middle East. Companies such as Yukong, Hyundai and Samsung have ambitions to become fully integrated oil firms on an international level.

Table 9. Oil-refining capacity and exports in the Republic of Korea
(Thousands of tonnes per year)

	Capacity		Exports
	1989	1991	end-1991
Yukong	325	545	50
Honam	380	400	30
Ssangyoung	90	300	150
Kyung In	90	225	30
Kukedong	90	100	20

Source: Far Eastern Economic Review, January 1992.

The Republic of Korea has exhibited the most rapid growth in demand for oil in the world in recent years, and this has led to a massive expansion in domestic refining capacity (from 850,000 barrels per day in 1988 to nearly 1.6 million today) at a cost of $4 billion, which raised the industry's debt to $9.7 billion by 1990. The second consequence of the capacity expansion was a surplus of approximately 400,000 barrels per day which fuelled an export drive to neighbouring markets, thus driving down refining margins and inducing cutbacks in output in Japan, Singapore and elsewhere in the region. The rapid growth in the energy demand of the Republic of Korea, occurring at an annual rate of 16% between 1987 and 1991 for oil products, should absorb the surplus capacity in a few years, but in the meantime domestic refiners will face serious difficulties in maintaining any semblance of profitability, while they continue to look to export markets to dispose of excess production. Exports amounted to some 300,000 barrels per day in 1991 and should remain at a similar level in 1992.

One characteristic of refineries in the Republic of Korea is their relative lack of sophistication and hence their inability to process higher-value-added refined products (e.g., naphtha). Output is therefore expanded to obtain a greater amount of light refined products and by-products (e.g., fuel oil) which are then exported. The lack of upgraded capacity has led to new plans for a massive $6 billion investment over the next five years in order to correct for this, although many people are not convinced that the industry itself can generate this kind of financing.

With the growth of energy demand in the Republic of Korea, the first signs of government deregulation of the oil industry, and the current difficulties and ambitions of the refiners, many foreign companies have shown great interest in participating at several stages of the industry. In September 1991, Saudi Aramco bought a 35% share of Ssangyoung for $400 million, and Abu Dhabi National Oil Co. and Total of France are interested in acquiring a 25% share in Kukedong. Other companies interested include BP and Royal Dutch/Shell. Deregulation in the oil-refining business is proceeding very cautiously, however, in part due to the lessons learned from the earlier deregulation of petrochemicals, an action that led to massive overcapacity in naphtha-cracking which will take several years to eliminate. For this reason the authorities are unwilling to allow a sixth refiner to enter the market and are thus resisting the efforts of Hyundai and Samsung (and perhaps Daewoo) to build refineries in the Republic of Korea. In 1991, many of the *chaebol* (large conglomerates) chose petrochemicals and chemicals as one of their areas of concentration for the 1990s, after the Government pressured them to specialize (see table 10).

The market for petroleum products has risen rapidly in recent years due to the growth in automobiles, the shift to kerosene and gasoil, and the growth of demand for electric power as a result of residential construction. Between 1987 and 1990, petrol consumption rose by 29%, and similar increases have occurred in other, lighter refined products such as kerosene and diesel fuel. Thailand is the only other country to have displayed comparable growth rates in petroleum demand, while Japan, Indonesia, Taiwan Province of China, Malaysia, the Philippines and Singapore have maintained an average of only 8% and 2-3% per annum in the United States and the European Community, respectively. In the medium run, demand for all petroleum products is likely to reach an average rate of 7.5% per annum during 1992-1996.

(b) Reducing dependence on Middle Eastern oil imports

The Government of the Republic of Korea has long supported efforts to reduce the country's energy import dependence, paying particular attention to oil exploration abroad as a means to achieve this.[15] The aim until recently was to obtain 20% of daily oil requirements from equity crude owned by the Republic of Korea by the year 2000. This target has now been abandoned as all but impossible given an estimated daily requirement of 1.7 million barrels per day as compared to 1.1 million barrels per day today. Many companies have been involved in oil exploration abroad. In December 1991, a five-year consortium between the Republic of Korea and Indonesia, aided by $217 million from the Government of the Republic of Korea and operating the West Madeira field north of Java was abandoned. A second failed attempt was the Yukong experience in Myanmar. Overall, current equity crude owned by the Republic of Korea is only 22,000 barrels per day (1.8% of daily consumption), with 20,000 of this coming from the Barib block in Yemen and 2,000 from an oil field in Egypt.

The experience in Yemen is perhaps indicative of future developments whereby the inexperienced companies of the Republic of Korea leave exploration to other companies and then participate in proven fields as non-operators. Yukong, which bought the largest stake in Yemen from the United States company Hunt Oil in 1984, is very active in other projects. It participates in nine exploration areas in eight countries, including Egypt, Yemen, Australia and Malaysia. Other large conglomerates such as Hyundai, Samsung and Lucky-Goldstar have also been actively searching for overseas oil in line with their ambitions in the international oil business. Hyundai, for example, formed, in August 1990, Hyundai Resources, to undertake

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[15] *Far Eastern Economic Review*, January 1992.

Table 10. Ten largest groups and their selected companies, Republic of Korea

Group		Selected subsidiaries
1.	Samsung	Samsung Shipbuilding and Heavy Industries Samsung Electronics Samsung General Chemicals
2.	Hyundai	Hyundai Motors Hyundai Petrochemical Hyundai Precision Industries (shipbuilding)
3.	Lucky Goldstar	Lucky Limited (petrochemicals) Goldstar (electronics) Goldstar Electron Devices
4.	Daewoo	Daewoo Corporation (textiles, construction trading) Daewoo Electronics Daewoo Shipbuilding
5.	Sunkyong	Yukong (oil refining) SKI (textiles) SKC (audio and video tapes)
6.	Ssangyoung	Ssangyoung Cement Ssangyoung Oil Refinery Ssangyoung Motors
7.	Hanijin	Korean Airlines Hanil Development (construction) Hanjin Shipping
8.	Hyosung	Tongyang Nylon Hyosung Heavy Industries Hyosung Corporation (trading)
9.	Korea Explosives	Korea Explosive (chemicals) Kyungin Energy (oil refining) Hanyang Chemicals
10.	Kia	Asia Motors Kia Machine Tool Kia Steel

Source: Republic of Korea, Office of Bank Supervision and Examination.

extensive exploration in the former Soviet Union. The company, together with Broken Hill Pty of Australia and Amoco of the United States, is battling with other consortia (e.g. one between Exxon and 16 Japanese trading companies) for the right to develop the rich oil (680 million barrels) and gas (16 trillion cu.ft.) areas around Satchalin Island, at an estimated cost of $10 billion. The company is also conducting a feasibility study for oil prospects in the Kalmyk region near the Caspian Sea, and four other areas, including the Mangyshlak region of Kazakhstan.

Some oil analysts question the wisdom of oil exploration as a way to reduce reliance on sources outside the Republic of Korea. Rather, they point out that the Government should instead be attempting to create a proper balance of oil imports, that is, diversify its sources of supply. At present, the country is heavily reliant on the Middle East, which supplies 75% of the country's oil. Diversification would involve a new balance between short- and long-term contracts and between national oil companies and international oil companies.

(c) Petrochemicals

From virtual non-existence in the early 1960s, the chemicals industry of the Republic of Korea has grown impressively over the last two decades, assuming its present dimensions, and is still growing fast (see annex II). In large part this is the result of the strong emphasis placed by the Government on the development of a domestic chemicals industry from the late 1960s onwards. Following the two oil shocks of the 1970s, the industry moved from commodity-resins production (polyvinyl chloride [PVC], high-density polyethylene [HDPE], polypropylene [PP], and polystyrene [PS]) towards higher-value-added materials and advanced polymeric materials such as high-function polymers, specialty polymers, liquid crystals and biopolymers. Interestingly, the rising demand, albeit at an early stage, for engineering plastics has prompted several companies to enter or plan to enter this area.

Polymer production in the Republic of Korea is following two major thrusts. First, there is an emphasis on the expansion of commodity plastics, man-made fibres and synthetic rubbers aimed at satisfying the domestic mass markets in these low-end products. Secondly, there is increasing emphasis on the production of higher-value-added and new materials, utilizing advanced synthesis and processing technologies. This is considerably more difficult and involves the active collaboration of university, industry and government research centre and laboratory. Moreover, foreign companies are called upon to participate in the process of technological upgrading and the move towards specialties and engineering polymers.

The recent liberalization measures at the petrochemicals stage of the industry have meant a large expansion in naphtha-cracking capacity, creating a massive surplus capacity in basic petrochemical feedstock for the rest of this decade. Companies involved in this field are therefore trying to increase exports of plastics, fibres and resins to regional markets, including the vast emerging Chinese market, and are also entering into agreements with Japanese chemical companies. Furthermore, instead of exporting basic petrochemicals to the South-East Asian markets, the Republic of Korea is displaying considerable interest in utilizing the large existing research potential in polymers to move into specialties and advanced polymer materials. The Government is convinced of the importance of this research area and has included it under a national project. Government research centres and the industry have therefore embarked upon research programmes aimed at replacing commodity chemicals with fine chemicals, specialties, engineering polymers and composites. A difficulty here is the still-small domestic market for advanced polymeric materials.

In effecting this transition, the 600-strong Korean Research Institute of Chemical Technology (KRICT) established over 12 years ago is playing a crucial role. The central aim of the Institute is to assist the chemical industry in the Republic of Korea to transcend its role of technology importer and learner to that of originator and developer. The Institute is playing a catalytic role whereby chemical producers in the Republic of Korea begin the independent development of new materials, compounds and chemical technologies, thus reducing the excessive reliance on foreign technology transfer or alliances with foreign firms, which do not always work to the benefit of local firms. At the same time, KRICT recognizes that collaboration with foreign companies is both necessary and could prove beneficial in preparing the science and technology base that can subsequently be used by domestic companies. Moreover, it is accepted that access to the global pools of scientific and technological knowledge is absolutely essential in order to keep ahead of developments and establish or maintain a lead in certain areas.

Industry has become interested recently in new materials and fine chemicals but faces serious difficulties. Until 1989, there was a shortage of plastics because of the production levels and exports of the major user industries in automobiles and electronic consumer durables. Companies therefore did not have the incentive to engage in much research and concentrated instead on commodity plastics. With the emerging overcapacity in polymer-based materials the need to enhance value added before export has become more pressing. This need is likely to be accentuated by the increasingly stringent performance requirements of domestic user industries as they compete in higher-value-added segments of the world and regional markets in the 1990s. It is in this context that KRICT can assist industry to overcome its deficiencies in conducting R&D in polymer blends and composites.

In August 1992, the Ministry of Science and Technology (MOST) announced details for 3 of the 14 proposed research areas for the "Highly Advanced National Project" which aims to propel the Republic of Korea to the status of G-7 economies by the year 2000.

The three projects relate to new pharmaceuticals and agrochemicals, new advanced materials and new functional biomaterials. In 1992, about $34 million was to be spent on these projects. Over 20 government laboratories and institutes, 50 universities and 60 private companies were to participate, and a key role is assigned to the two government institutions, namely the Korea Institute of Science and Technology (KIST) and KRICT, while major private-sector participants include large conglomerates such as Daewoo, Samsung and Hyundai as well as many pharmaceutical companies. A large share of funding is intended for pharmaceuticals and particularly new drugs and vaccines, especially antibiotics. Many companies and universities are participating, led by KIST and KRICT. In addition, two new non-profit government/industry consortia have been set up: the New Medicine Development Consortium and the Genetic Engineering Research Consortium.

Overall, the new projects confirm the trend toward heavy emphasis on fine chemicals, advanced polymers, composite materials and biodegradable polymers.

4. *Taiwan Province of China*

According to a recent study, Taiwan Province of China possesses enormous potential and opportunities and capabilities for the development of advanced polymers, utilizing internal strengths and alliances with foreign companies, at every stage from raw materials to intermediates to resins and fibres to fabricated advanced composites and plastic parts. The following fields are under active and serious consideration:

(a) Engineering thermoplastics: Polycarbonate, polyphenylene sulphide (PPS), liquid crystal polymers (LCP);

(b) High-performance fibres

(i) Fusible fibres based on PPS, PES and PEEK (polyetheretherketone);

(ii) LCP fibres;

(c) Compounds and prepregs

(i) With fibre and mineral reinforcement;

(ii) With polymer alloys and blends.

A first step involves enhancing expertise by servicing domestic industries which export to the world market. This will enable the industry to compete later on in the world market. The strategy of selective, stepwise acquisition of skills in engineering thermoplastics, high-performance fibres and composite parts necessitates securing upstream raw materials at competitive prices, building up automated processing and fabrication plants and equipment, and captivating domestic high-volume user markets (e.g., in leisure or automobiles). It would also help to have access to key technologies, markets and distribution systems, including strategic alliances with foreign firms, licensing and in-house R&D. A crucial role in the capability build-up will be played by the Industrial Technology Research Institute (ITRI) and the Chung Shan Institute. The Materials Research Laboratories (MRL) and Union Chemical Laboratories at ITRI possess several key technologies that can be transferred to local industry (see annex III).

IV. ADVANCED MATERIALS: THE NEW MANUFACTURING AND GLOBAL COMPETITIVE ADVANTAGE

In the preceding sections, the far-reaching transformations under way in the materials sector were identified. These have been brought on by the enhanced ability of materials scientists to intervene at the atomic and molecular levels of the structure of matter in order to process both traditional and entirely new materials with desirable properties and end-use performance characteristics. The materials sector is beginning to be characterized by multidisciplinary and multi-materials competencies, accelerating materials invention and innovation, variety, tailorability and customization to end-use specifications, while forging greater vertical linkages with users in high technology and other sectors in manufacturing.

At the same time, the manufacturing industry is undergoing fundamental restructuring with new patterns of organizing production and micro-electronics-based automation technologies diffusing slowly across a spectrum of firms and industries. The fragmentation of market demand, globalization of production and of marketing and the consequent intensification of competition necessitate product differentiation, market niching, faster product renewal and speedier, more flexible market responses. The transition by advanced industrialized economies towards a new techno-economic, socio-institutional and managerial paradigm is beginning to be recognized as one of determining influence in the global redivision of labour and prospects for industrialization and export-oriented manufacturing activities in the developing economies of the ESCWA region, Africa and Latin America.

Clearly, merging the scientific and fabricating capabilities of new materials with the new methods of organizing production in manufacturing raises theoretical, empirical and policy-related issues: What internal managerial and organizational requirements and changes do the new materials' multidisciplinary, multi-materials and R&D requirements imply for firms in basic industries? What internal and external strategies and options are available? How do firms cope with and behave in satellite subcontracting roles, horizontal coordinations and autonomous problem-solving? Are quasi-permanent, stratified groups of subcontracting suppliers necessary and are they more widespread than the automobile example? How does the resolution of these internal and external imperatives impinge upon the international competitiveness of firms and national industrial structures? What are the implications of the new realities in the global materials and manufacturing market for the location of industry and the prospects for manufacturing in newly industrialized economies (NIEs)? And, most importantly, what are the implications of the new materials and manufacturing circumstances for science, technology and industrial strategies in both middle-income and low-income developing economies? Progress in conceptual clarity, understanding and theoretical explanation can only be achieved through a detailed empirical study of emerging patterns of organization and the strategies of firms and industries throughout the world.

A central theme of this study focuses on the need to tie the analysis of strategies in materials-related technologies to both the revolution in the science and engineering knowledge-base of materials production and to the new global market circumstances in which industry competes.

In chapter III, the major features of the restructuring of industries that produce basic materials were brought out. This restructuring is taking place under the manifold influence of a slower rate of growth in demand, saturation of many product lines, deep and prolonged recessions, overcapacity, declining profit margins and the emergence of a new scientific and engineering base in materials design, production and use. This gradual, albeit far-reaching, transformation and the global redeployment of basic industries over the last two decades certainly did not occur in a vacuum. Rather, they are closely related to, and increasingly form an integral part of, the ongoing transition to new forms of industrial organization and the emergence of the new manufacturing methods. What may be called, as a convenient summary term, post-Fordism is not only diffusing within manufacturing and service industries but, interestingly, is also beginning to permeate the materials-producing industries themselves in such areas as flexible fabrication methods, market segmentation, flatter management hierarchies, labour multi-skilling, continuous improvement, higher quality and getting close to the customer. Such developments, of course, are in marked contrast to Fordist mass-production practices characterizing most of basic manufacturing industries in the post-war period. Hence, what is currently observable is the "fusion" or "merging" of materials production with manufacturing industries, both of which are shifting towards flexible, high-variety methods of production utilizing economies of scale.

Furthermore, the pace and terms of competition are today set by the rise of world-class manufacturing producers employing a new set of weapons to continually improve performance, service and cost-effectiveness. Design is now at centre stage, and simultaneous engineering, where product and manufacturing process design are done simultaneously, provide a major source of competitive advancement. New materials reinforce the need for a simultaneous approach and provide a major new weapon in world-class manufacturing.[16]

A. The transition to new forms of industrial organization

1. *From Fordist to post-Fordist methods of industrial organization*

The last two decades have borne witness to the gradual dissolution of the post-war patterns of mechanization and work organization, which were based on inflexible, mass-production techniques and associated management structures and practices. Industry has been undergoing fundamental restructuring during which there has been a discernible shift away from Fordist production methods and towards increased flexibility. The emerging paradigm is variously described as post-Fordism or flexible specialization or even Just-in-Time (JIT), although this last description is not entirely correct.

Fordist mass-production methods employ the principles of increasing division of labour, fragmentation of tasks, mechanization of tasks, the use of dedicated pieces of machinery and moving production lines, together with Taylorist principles for managerial control of work via the separation of direct from indirect tasks, complete job specification and removal of any worker control over the work flow. Profitable production under this multilayered and hierarchical labour-management system, in which skill, initiative and creativity are mostly eliminated, requires uninterrupted, high- volume output of standardized products aimed at mass markets. Production here is supply-driven and utilizes substantial work in progress and finished-goods inventories to offset faults and quality problems as well as to meet fluctuations in market demand. Dedicated plants, machinery and production lines make sense under conditions of high volume, small product variety, long product life-span and a stable macro-economic environment in which incomes and tastes can accommodate the outflow of mass-production lines.

Mass production, as the dominant paradigm in industrial organization, fared well for much of the high-growth period in the 1950s and 1960s. Nevertheless, apart from (a) the onset of macro-economic instability in the 1970s; (b) exchange-rate fluctuations following the breakdown of the Bretton Woods fixed-exchange-rate arrangements; (c) accelerating inflation; and (d) a slow-down in economic growth after the first oil shock in 1973, mass production was further undermined internally. A very discernible deceleration in productivity growth rates

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[16] Quality, continuous improvement and getting close to the customer are strongly emphasized by Alcoa in the United States.

became apparent in a wide range of industrial sectors from the late 1960s onwards. At the same time as existing technologies offered decreasing potential for further technical change, several industries began to experience serious problems with worker boredom, turnover rates, alienation, absenteeism, indifference to quality and resistance to change. Together with rising inventory costs and slower growth as well as unstable and fragmented demand patterns, these developments placed tremendous pressures on profitability and ushered in concerted efforts toward finding appropriate solutions to the new circumstances. Market niching and product differentiation can therefore be seen as a deliberate attempt by firms to salvage profitability and market share in declining, saturated markets.

Declining growth rates and evidence of market saturation in a range of consumer durables in the 1970s combined with increasing fragmentation and instability in market demand as well as ever more sophisticated consumer preferences necessitating higher-quality, low-volume production of different products with shorter life cycles. Clearly, the inflexible manufacturing methods and accompanying inventory systems characterizing Fordist production lines became increasingly ill-suited to the conditions of evolving market niches, product differentiation, consumer sophistication, customized production, and fast-changing market circumstances. Here, greater variety is needed in small lot sizes, while firms must become more flexible and maintain close contact with the markets in order to recognize and respond speedily to market fluctuations and changing demand patterns. Shorter production lead-times, shorter order-processing and fast market responsiveness have, in fact, become important weapons in time-based competition in world markets.

2. *Post-Fordist practices in materials production*

The diffusion of new best-practice-flexible-manufacturing technologies throughout industry and the concomitant demands in terms of new materials, highly stringent technical specifications, quality, flexibility and customization are beginning to influence the management practices, work organization, and manufacturing processes employed in the materials industries themselves. The forces making for an integration of materials producers and users are also working towards a reorganization of the former in order to meet the evolving needs of user industries in both quality and performance but also in flexibility, product differentiation and customization. The restructuring of basic industries in the 1980s was also accompanied by a flattening of hierarchical structures in management, organizational change at the point of production, flexible work practices, multi-skilling, greater autonomy, flexible automation technologies and economies of scale as well as customized production for segmented markets further downstream.

For decades, the dominant mode of production in materials involved large-scale mass production of standardized primary and processed-metal and chemical commodities entering mass-production industries. The size of the minimum efficient-scale plant, mines, smelters, refineries and rolling mills was forever increasing as unit cost was a prime determinant in the choice of materials entering final products. The management practices and structures, management-labour relations and plant sizes associated with the mass-production paradigm are becoming inappropriate in today's market-place. Scale economies, of course, remain important, especially at the earliest stages of materials extraction and primary transformation, even though new processing technologies, alloying techniques and quality improvements are introducing new parameters into these traditional activities. Further downstream, materials markets are beginning to be characterized by:

(a) The rising importance of quality (reliability, consistency and durability) as inseparable from cost in product differentiation;

(b) Segmentation by performance requirement;

(c) Smaller size than those of commodity materials;

(d) The need to engineer monolithic and composite materials to meet a variety of very stringent design and performance specifications;

(e) The need to employ new flexible manufacturing technologies to attain economies of scale, increasing diversity while reducing scale;

(f) The need to produce higher-value-added materials in order to amortize high capital costs and R&D costs;

(g) The need to meet the dramatic reduction in product-development time;

(h) The need to resolve environmental impact of products and processes and design them for disassembly and recyclability.

This is the new materials environment in which traditional materials firms increasingly find themselves as they move away from standardized commodity production to high-value-added downstream stages of production and diversify into related and advanced materials businesses.

3. *New materials in post-Fordism*

The whole of the materials sector is permeated by the insights of the revolution in MSE. It is restructuring and it is also integrating more closely with a manufacturing base characterized by highly segmented materials input requirements requiring flexible, customized, performance-dominated materials production (see figure 31). Moreover, the new circumstances require a close integration of materials design with component and product design in manufacturing.

4. *Changing markets, production technologies, materials and management systems*

As the preceding paragraphs indicate, there has been quite a remarkable transformation in the global manufacturing market-place over the last 10-15 years. A central aspect concerns the internationalization of production and the blossoming of new markets. Business entities now compete in a widening range of consumer and industrial products in global markets. The interpenetration of markets, accompanied by the rise of major new competitors in manufacturing activities from the Pacific rim and Latin America, has intensified competitive pressures on firms unable to shield themselves behind the protection of the home market.

The globalization of business has meant a rethinking of both product design and marketing strategies in the context of the world market and segments thereof. But more than this, the intensification of competition has led to reduced product life cycles and parallel pressures for faster product renewal, which has been evident in several industries in recent years. If the ratio of new-product-design lead time to product life cycle is constant, then almost every product will increasingly fall prey to a continuous shortening of its life cycle, given the rising potential afforded by advances in CAD/CAM/CAE to design, redesign, and manufacture products and bring them to market more rapidly than ever before. Time is therefore of the essence here, and it is emerging as a major source of competitive advantage and profitability for firms able to engage in faster product innovation and shorter time to market.

Moreover, the new market realities elevate design to the centre stage in business. One of the reasons for declining product life cycles is the increasing sophistication, knowledge, discriminatory powers and demanding requirements of the consumer. Consumers are far more discerning in their choice of products on the basis of technical performance characteristics and functions, specifications, quality and appearance. Firms must therefore get close to the increasingly sophisticated customer in order to identify and rapidly satisfy his needs while facing fierce competition from other firms trying to do exactly the same in nationally and globally segmented markets. Product design and development lead cycles, time to market and innovative designs of high-quality, differentiated products tailored to the needs of specific market niches are therefore crucial for survival in today's market-place.

Nevertheless, design is not to be thought of as a separate business function divorced from the rest and as the first step in a sequential, time-consuming and costly process of product development and manufacturing. Although this is the traditional (and still prevalent) view of design, it must be seen, rather, as an inseparable part of manufacturing operations, finance/accounting, marketing/customers and suppliers in the context of creating a world-class company. Thus, design not only acquires central importance under the current circumstances but becomes a prime mover in integrating the diverse business functions of manufacturing, from suppliers to production engineering to marketing, and this is a prerequisite for competitive advantage in today's customer-driven markets.

5. *A new competitive environment: the need for flexibility*

New methods of organizing production and new micro-electronics-based automation technologies are being developed in response to changing markets and competitive pressures that all firms are now beginning to experience.

Firms operate in a competitive environment which places a premium on—indeed necessitates—greater flexibility at several levels of operations. Greater variety, rapid volume changes, the need to offer products aimed at specific market niches and individual consumer preferences, the need to offer more frequent product modifications and to introduce a greater number of new products in ever decreasing lead times intensify competitive pressures and problems faced by management steeped in traditional methods of organizing and managing production. Today, companies must aim both at high productivity and greater flexibility, as opposed to the traditional trade-off between these two goals in manufacturing.

The competitive pressures for more flexible manufacturing processes and market responsiveness combined with close attention to individual customer requirements are manifesting themselves throughout industry and not merely in final consumer goods. Processing industries such as petrochemicals and food must increasingly move from volume to variety. Synthetic fibres experience shorter production runs due to trends in clothing, while margarine/edible oils also have been obliged to adapt to higher variety due to changing consumer preferences. In petrochemicals greater emphasis is placed on higher value "white goods". Metal fabricators need to generate small quantities of specialty products aimed at specific market niches. Mass production and assembly of consumer durables such as cars need to move away from high-volume output of a narrow product range yielding high productivity and low unit cost, concentrating instead on more "flexible mass production" of high variety at low unit cost. Until recently the predominant strategy in process industries and mass production was predicated upon large-scale investment in dedicated plant and machinery. Where volume is high enough, in both intermediate and final standardized commodities, dedicated machinery still makes sense. However, where a greater number and variety of products are required, in smaller volumes, flexible manufacturing methods must be introduced.

B. ADVANCED MATERIALS, SIMULTANEOUS ENGINEERING AND COMPETITIVE ADVANTAGE IN WORLD-CLASS MANUFACTURING

1. *Simultaneous engineering*

Underlying world-class manufacturing is a process of continuous improvement, close attention to customer needs, flexibility and fast market responsiveness, and a need to integrate business functions, i.e. design, manufacturing, accounting, marketing and supplier relations. The benefits of close, long-term collaboration with and cultivation of a small number of select suppliers in the context of JIT and the Japanese *keiretsu*[17] system of production have been well documented in the management literature[18] and need not be elaborated on here.

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[17] There are three types of *keiretsu*. The first is the capital-based *keiretsu* (including former *zaibatsu*) which consists of a loose federations of independent firms clustered around a bank and a trading company, with cross-shareholding common. With the rise of electronics and high technology, the industrial *keiretsu* component of the capital *keiretsu* gained significance in which capital forms the basis of inter-firm relations. The second is production *keiretsu*, mainly observed in automobiles, which exhibits vertical integration between manufacturers and suppliers. It is characterized by stable, long-term relationships between the manufacturer and the first-tier primary subcontractors, which then subcontract to thousands of second- and third-tier suppliers, all of which are tied into the production process of the manufacturer. The relationship involves reciprocal, but not necessarily equal, obligations, in the form of provision of long-term, stable contrasts and a constant flow of managerial, financial and technological support on the part of the manufacturer, and commitment to high-quality, low-cost components on the part of the suppliers. The latter receive detailed specifications from the manufacturers as regards quality, production runs, delivery schedules and prices to which they must adhere. Many first-tier suppliers possess considerable technological sophistication and become involved in component and product improvement and design. The last category involves the sales-distribution *keiretsu* which integrate vertically with distribution channels from factory gate to retail outlets.

[18] R. Schonberger, *Japanese Manufacturing Techniques*, Free Press, and R. Schonberger, *World Class Manufacturing*. T. Kaupe and P.T. Bolwijn, "Manufacturing: The New Case for Vertical Integration", Harvard Business Review, March-April 1988. "The Coming of the Japanese Keiretsu", Harvard Business Review, and "Keiretsu", Tokyo Business Today, September 1990.

Instead, the focus should be on the role of new materials as an irreversible force necessitating backward and forward vertical integration and collaborative alliances between suppliers and users in industry. The concept of simultaneous engineering (or concurrent engineering or simultaneous manufacture) underlies many of the integrative changes described above and is beginning to be recognized as a necessary weapon in the armoury of world-class manufacturing.

In essence, simultaneous or concurrent engineering means that the design of the product and its associated manufacturing process is done simultaneously, incorporating interdisciplinary teamwork throughout design manufacturing, marketing and suppliers. Viewed somewhat more narrowly, it requires that manufacturing engineering be introduced at a very early stage in product development to influence the conceptualization, design, development and manufacturing of the product. On the other hand, it greatly enhances the influence of design over the manufacturing process (see figure 32).

2. *New materials and simultaneous manufacture*

All firms are today faced with the need to adapt to new energy conditions, changing market circumstances and the onset of organizational change and micro-electronics-based automation technologies. The concept of simultaneous manufacture and design for manufacture/assembly are logical consequences of the need to compress product-development time as well as simplify and improve the manufacturing process, building in product quality and reducing costs. It is not sufficient, however, given the advent of new materials and their attendant organizational and technological characteristics. New materials are never a straight replacement for an existing material in a particular application. In order to take advantage of the constellation of enhanced properties and design potential, there must be a redesign of both product and manufacturing process. Near neat shaped fabrication technologies enable a simultaneous-implication-product-design and a reduction of its component parts and assembly operations. This is enhanced by the advent of new joining techniques and adhesives which do away with traditional mechanical fasteners to hold discrete parts. Moreover, the application of CAD/CAM to the design and production of complex, sophisticated dies and moulding equipment is facilitating a greater diffusion of engineering polymers and other new materials. The gradual resolution of processing constraints in advanced composites, through less reliance on human skills and greater automation of tape-laying operations (e.g., CNC tape-laying and epoxy-coating equipment), together with entirely new processing and coating technologies in advanced ceramics and metals (which are revolutionizing traditional metal working operations while vastly improving metal properties) are laying the foundations for generalized acceptance and diffusion of new materials in industry. The production and diffusion of new materials is therefore revolutionizing production methods in materials-producing industries and also acts as a powerful agent for change in product and manufacturing process redesign, renewal or replacement in user industries.

3. *From simultaneous manufacture (SM) to materials-based simultaneous manufacture (MSM)*

In simultaneous manufacture (or engineering) the design of the product and of the process making it becomes a simultaneous rather than a sequential process. Materials selection enters at an early stage, and the logical implication of the concept is that there is at least

Figure 31. The integration of materials-producing and -using industries in the new materials and manufacturing era

MATERIALS PRODUCERS

The Revolution in Materials Science and Engineering →

- Mastery over Master: Understand, predict, control, create new forms and control its form and uses.
- Materials synthesis/processing, and the structure, properties, performances continuum across all classes of materials.
- Multi-disciplinary and multimaterials competences
- Role of pure science much enhanced
- Expensive, complex materials research, testing and characterization technologies
- Need for interfirm alliances and Government-industry consortia
- Integration of MSE with final product and process design in manufacturing
- Integration of materials producers and users

The Restructuring of Basic Industries

- Divestment, consolidation and redeployment of commodity metals and chemicals
- Move downstream to high value-added fabrication and specialties
- Diversification into related business and advanced materials
- Inter-firm alliances
- Transformation of traditional chemicals and metals companies into large global materials MNCs
- Transition from metals-based to materials economies
- Segmented markets, stringent specifications, tailorability, quality, flexibility, economies of scope
- MSE-based, computer-aided final product and manufacturing process design
- Collaboration and proximity to user industries globally

↓↑

High Tech Industries eg Aerospace, Microelectronics ⇄

- Materials constrained complex and generic technologies, across aerospace, electronics, computers, energy, high-temperature pro;cessing and biotechnologies
- In-house materials R&D and backward integration for captive supplies
- Need for tailored materials systems to meet exceedingly complex and technically stringent product design specifications in specific market segments
- Synergy between diverse scientific fields and technologies
- Cross-border inter-firm alliances and joint research programmes

Manufacturing Industries eg Cars, Consumer Durables, Machinery

- Fragmentation of market demand
- Globalisation of markets and production
- Intensification of competition
- Accelerated product obsolescence
- Fast product renewal
- Time based competition
- Collaboration between suppliers-customers (keiretsu)
- Implementation of organisational change (JIT, Continuous improvement, TQC)
- Flexible manufacturing technologies (CAD/CAM, CIM)
- Design for Manufacture, Assembly and Disassembly
- Materials based product and process design

MATERIALS USERS

Source: L.C. Kaounides, 1992.

collaboration with materials and components suppliers in the design process. CAD/CAM/CAE provides powerful tools for simultaneous product and manufacturing design, finite element analysis, prototype computer simulation and data transmission to the manufacturing process, indeed necessitating a simultaneous approach.

The proliferation of new metals, engineering plastics, ceramics and composites makes it essential that product-development engineers have access to computerized materials databases in simultaneous engineering or manufacture. The significance of new materials, however, goes far beyond a mere proliferation in the number of materials and properties available to design engineers, important though this is. Rather, new materials now necessitate a simultaneous product design and manufacture approach throughout manufacturing. To take advantage of the superior properties and performance of new materials, products must be freshly conceptualized and redesigned. The use of a new material will also determine the way the product is manufactured and vice versa. Hence, the material, product and manufacturing process must be conceived simultaneously in the context of total lifetime systems cost approach. (See figure 33.)

With the onset of new and advanced materials and processing technologies, the existing tendency in industry toward the implementation of simultaneous manufacturing (SM) techniques is already being transformed unavoidably into the richer and more powerful materials-based simultaneous manufacture (MSM) approach.[19] Economies in possession of a critical minimum of materials synthesis and processing capabilities as well as the institutional and organizational structures to permit the speedy transmission of science-based inventions into tailored commercial applications will gain technological superiority and cumulative competitive advantage in the world markets of 1990s.

C. THE CONVERSION OF SCIENTIFIC AND TECHNOLOGICAL ADVANCES IN NEW MATERIALS INTO INDUSTRIAL AND COMMERCIAL APPLICATIONS

There is currently much debate, especially in the United States on the need for an industrial or technology policy and on what form it should take, given the historical lessons provided by the Japanese experience, the challenge posed by Japan in a series of high-technology industries (e.g., semi-conductors, and now opto-electronics and biotechnologies), and the attempts by Taiwan Province of China and the Republic of Korea to emulate the Japanese example. Much emphasis is placed on the increasing role of basic science as the source of the foundations for innovative new ideas, products and technologies, and the parallel need for speedy and efficient transition of emerging new technologies into commercial and industrial applications. Biotechnologies are seen as the archetypal example of a science-based industry in which new inventions are quickly employed in commercial applications, pointing the way in which other science-based industries are heading into the next century. The United States administration is consequently placing a much greater emphasis on supporting basic science, albeit with an orientation towards commercial application. Moreover, powerful voices have

[19] Hence the role of materials suppliers becomes crucial for the innovation and competitiveness of firms, industries and economies in the 1990s and beyond. See the forthcoming paper by Professor J. Chelsom (formerly of Ford Motor Company) and Lakis Kaounides "Materials Suppliers and Simultaneous Engineering in the 1990s", City University Management Systems Department and Business School, London, U.K., November 1992.

been raised in the United States for greater government-university-industry collaboration, which would facilitate the transformation of scientific invention into domestic industrial application.

However, as the above analysis makes clear, materials synthesis and processing have acquired a preeminent position in the generation of new technologies and their commercialization, linking the basic sciences to the engineering and manufacturing base of the economy. Moreover, materials synthesis and processing, in the context of simultaneous manufacture, converts basic-scientific inventions into high-technology applications and fast product renewal, underpinning competitive advantage in world-class manufacture. However, this presupposes that an economy possesses considerable processing and engineering skills, a strong manufacturing base and university-industry-government collaborative mechanisms.

1. *Emerging national and business strategies*

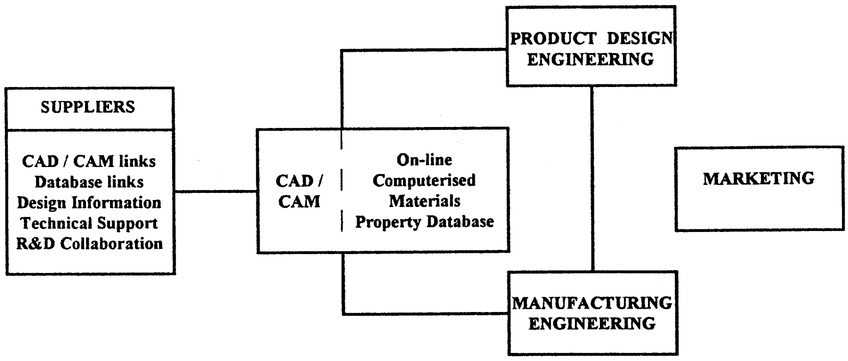
The materials sector is emerging as a science-based, high-technology sector on which all other new technologies depend for further technical change and growth. It is enmeshed in very rapid scientific and technological change on a globally dispersed front. A mass of domestic synthesis and processing capabilities is now recognized as being of paramount, importance for technical change in high-technology and other sectors in manufacturing, and in bringing the fruits of research quickly and efficiently into the productive sphere, facilitating innovative product design and gaining global competitive advantage. Of importance here are the differing mechanisms within national economies (such as collaborative schemes and university-industry consortia) which channel materials R&D into commercial application, an area in which Japan excels.

Materials R&D today is not merely multidisciplinary; it also involves complex and expensive laboratory facilities, instrumentation and characterization technologies, extreme-environment-measurement technologies and considerable capabilities in computer science, mathematics, modelling techniques and interpretation of vast quantities of generated data. Some technologies (e.g., synchronton radiation) are both essential and too expensive for even the largest companies; hence they can only be accessed through government laboratories. In these circumstances, no firm, industry, or economy can be self-sufficient. Access to fast-changing materials science and technology on a global basis is essential. Alliances between firms, universities and government research establishments becomes imperative. Links with the domestic and foreign scientific community cannot be avoided. At the same time, the in-house generation of scientific results and access to outside materials technologies becomes irrelevant unless it can be successfully and speedily translated into commercial application.

2. *Strategic questions and responses*

There is therefore a large array of issues facing management in materials related firms and industries. How does a firm build upon its existing strengths to acquire an in-house multidisciplinary and, gradually, a multi-materials scientific and engineering base? How does it build up competence in materials and processing technologies? What role should be given to inter-firm alliances in the process of diversifying and entering new and advanced materials technology?

Figure 32. Simultaneous manufacture



CHARACTERISTICS

* Simultaneous Product and Manufacturing Process Engineering: The engineering of entire products, systems or major sub-assemblies. The engineering of components or individual piece parts.

* Interdisciplinary Teamwork and Optimisation of Design and Process.

* Computer-Aided Design (CAD) and Computer-Aided-Manufacture (CAM): Use of computer facilitates close links between conceptual development, drafting and analysis. Use analysis during conceptual development. Build analytical models. Eliminate costly phototyping and integration. Solid modelling. Expert systems. Computer networks.

* Computerised Materials Property Data Bases: Proliferation of materials necessitates that engineers have ready access to computerised databases containing continually updated materials availability and properties information. Organization of material properties in a manageable format. Search and evaluate materials for performance and cost. Integrate with CAD/CAM systems to support finite element analysis. Link materials selection to computer aided design. Candidate materials tested in optimised designs.

* Statistical Approaches to Eliminate Manufacturing Problems at the Design Stage: Statistical process control to gauge the accuracy of manufacturing methods. Statistical experimental design to improve quality and save costs by the generation of data necessary for the design of more reliable products and processes. Taguchi method and Robust Product Design method.

* Multiple, Interlinked Databases: Diverse hardware architectures used in design and manufacturing systems must work together. Different databases across engineering, manufacturing, marketing and sales must be able to interact. Given wide variety of data formats, databases although decentralized must be interlinked.

* Collaborative with Suppliers and Contractors: Formal and informal consultation with suppliers early in the design process. Firms may want direct computer access to contractors and suppliers databases and design information. Suppliers may need to install similar hardware and software systems for data management and exchange. Suppliers may need to demonstrate ability and skills in the use of statistical methods. Need to meet strict specifications and qualifications of user. JIT production and delivery.

ADVANTAGES

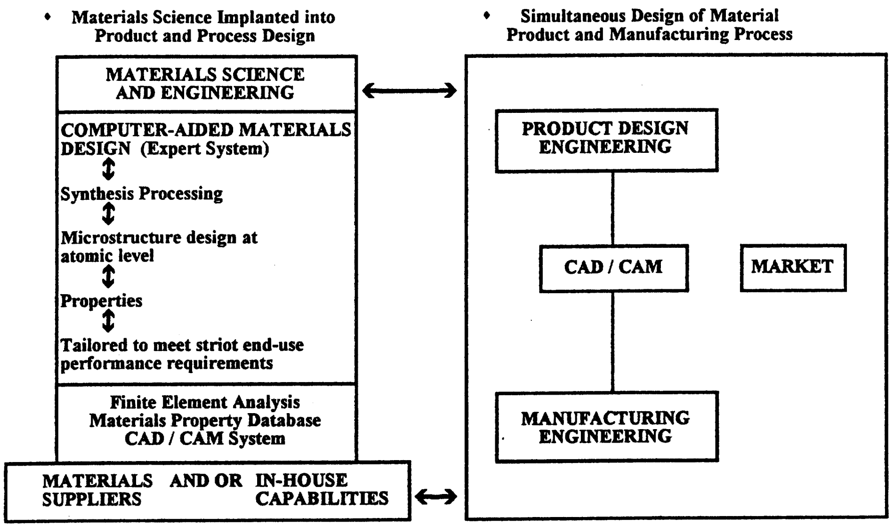
* Design Determines 80% of Manufacturing Costs: Hence manufacturing must be brought in early in the design process. Avoid fitting manufacturing process around already designed product. Avoid costly redesigns and process readjustments at a late stage.

* Design for Manufacture and Assembly: Simplify product and associated manufacturing and/or assembly process. Near net shape manufacture. Elimination of components, parts and assembly steps. Improve fitting and joining methods of components. Build quality into product and manufacturing process.

* **Results:**
  Compression of Product Development and Manufacturing Cycle.
  Improve time to the market.
  Less number of defects.
  Cost reduction.
  Closeness to customer, faster product renewal, faster market response.

Source: L. Kaounides; City University Business School, 1992.

Figure 33. Materials-based simultaneous manufacture
(New materials in world class manufacture)



SUPPLIER-USER INTERGRATION

* CAD/CAM linkages in materials and product design and manufacture within and between firms.
* Materials property database linkages and analysis underpinning design.
* Physical proximity for design collaboration; R&D and new materials/product development; technical support and servicing of customer needs; understanding of needs, quick decision making and response.
* Physical proximity for JIT delivery and quality.
* Suppliers expected to have high R&D and technical support capabilities for autonomous and co-operative new materials and component development.

CAPABILITIES OF MSM

* Design for Manufacturability and Assembly.
* Near Net Shape Manufacture.
* Design for Environmental Regulations, Safety, Disassembly and Recycling.
* Integration of Business Functions from Suppliers to Customers.
* Collaboration rather than Adversarial Supplier Relationships and R&D Efforts.
* Materials Invention Transmitted Fast into Commercial Application.
* Market Driven Materials R&D.
* Customisation of Materials for user requirements in complex engineering systems or end products.

ADVANTAGES OF MSM

* Cost Reduction (Total Systems Cost).
* Faster Product Renewal.
* Higher Quality (Consistency, Durability, Reliability).
* Higher Functionality, Knowledge-Intensity and Sophistication of End Products.
* Innovative Designs of Aesthetic Appeal.
* Meeting Stringent Technical Specifications for Advanced Manufacturing Technologies.
* Faster Technical Change in User Industries.
* Customised Products Aimed at Market Niches (Globally).
* New Materials for the Environment.

Source: L. Kaounides, 1992.

How does it keep up to date with fast-changing science and technology at the global level? How does it monitor, identify, acquire and use new technology, wherever it was originally developed, and what critical internal capabilities does this entail? How does it meet competition on a global scale and the formation of competing cross-border alliances? How does it move "closer" to the customer? How does it enter other markets and establish a presence near the customer? Is it essential in today's materials markets to establish a presence and/or technical support and facilities close to your customers? The answers vary from industry to industry, but certain common factors are emerging. The research, development and commercialization of new science-based advanced materials and processes increasingly involves collaboration amongst different firms: research contracts; minority equity investments; technology licensing; corporate alliances and joint ventures; mergers and acquisitions; consortia between industry and universities and/or government laboratories.

Few firms, if any, possess the comprehensive knowledge and expertise to develop all advanced materials or complex engineering systems involving a fusion of several major materials, micro-electronics, software and other technologies. Thus, collaboration within and between national boundaries is becoming a necessity in the 1990s as a means of building up the in-house science and technology base, staying up to date, sharing development and marketing costs and risks, and competing globally against other alliances. Together with in-house acquisitions of materials research and development, many forms of inter-firm technological and marketing collaboration have been developing in the materials field, in common with development in biotechnologies, micro-electronics and software. These trends naturally operate in the context of a fast transfer of technology across borders, a major feature of the new materials era. Both the requirements of inter-firm collaboration and a fast and free flow of technology across national boundaries while safeguarding the protection of intellectual property rights and national security pose considerable difficulties for policy makers. It has, moreover, important implications for the role of multinational corporations (MNCs) and the transfer of technology to NIEs and other LDCs (least developed countries) in the 1990s.

V. MATERIALS SCIENCE AND TECHNOLOGY STRATEGIES FOR THE TWENTY-FIRST CENTURY

A. Emerging strategies in the United States

A serious debate is currently under way in the United States as to the need for an "industrial" or "technology" policy and what form it should take.[20] It is recognized that under today's scientific and technological conditions, strong support must be provided for pure and applied scientific research in order to lay stronger foundations for technical advancement, competitiveness and growth. In January 1992, the Bush Administration raised the United States science budget by 7% to $13.4 billion and launched new initiatives in advanced materials (with an allocation of $1.82 billion for 1993, compared to $1.66 billion in 1992) and biotechnology (which is to receive $4.03 billion in 1993, compared to $3.75 billion in 1992). There is at present a discernible shift in United States science policy towards a distinct emphasis on the commercial application of research.

[20] See "Industrial Policy" (cover story), *Business Week*, 16 April 1992.

Several reports recently have laid special emphasis on advanced materials as a critical technology to United States competitiveness and its ability to attain or maintain a lead in high-technology sectors. For example, the Panel on National Critical Technologies laid special emphasis on the acquisition of materials synthesis and processing skills. Moreover, the Panel placed special emphasis on the need for United States industry to adopt an integrated and therefore continuous improvement approach to both product development and associated manufacturing processes. Given the strong United States science base, the parallel concern of the report centres on the need for a more effective transition of resulting technological advances into high-quality, high-performance, low-cost commercial products and military systems. The technologies selected are presented as shown in box 2.

The critical importance of materials synthesis and processing is also stressed in the important report by the National Research Council entitled Materials Science and Engineering for the 1990s and published in 1989. This theme was echoed in the follow-up report of the Materials Research Society,[21] which evaluates the requirements for implementing the Council's recommendations. The report makes the important (and somewhat surprising in the United States context) point that the United States now needs to move towards developing a "strategic, goal-oriented planning approach to materials R&D, involving industry, universities and government laboratories".

The two reports provided the key elements in preparing the Federal Programme in Materials Science and Technology[22] entitled Advanced Materials and Processing Programme (AMPP). The AMPP is influenced by three key findings:

(a) The need to enhance materials R&D activities, especially in synthesis and processing;

(b) The need to bridge the gap between basic understanding of materials and their technological applications;

(c) The need to involve industry, academia, and the Government in mission-oriented planning and the extension of R&D activities.

A multi-year, multi-agency programme is beginning in fiscal year 1993 in order to enhance the effectiveness of the federal R&D programme in Materials Science and Technology. The aim of the AMPP programme is to improve the manufacture and performance of materials, to enhance the nation's quality of life and economic growth. The AMPP will pay particular attention to the interfaces among universities, government laboratories and industry, and to the process of technology transfer from basic research to application. The AMPP is expected to add momentum to an evolutionary shift in United States materials R&D. Whereas R&D was oriented towards modifying natural commodities to make useful technologies, research and

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[21] "Report of the National Critical Technologies Panel", Washington, D.C., March 1991.

[22] "A National Agenda in Materials Science and Engineering: Implementing the MS&E Report", 1991. The report summarizes the results of four meetings across the United States involving over 400 participants from industry, academia and Governments.

development now increasingly concentrates on tailoring materials to achieve specific properties. The aims, implementing priorities and components of AMPP are given in figure 34. The funding of AMPP R&D by the federal agency is given in table 11.

B. Strategies in the European Communities

Within the European Communities there have been sustained and intensified efforts to improve industrial and materials technologies since at least the mid-1980s. The emphasis at the moment is on identifying community-wide trends and needs in materials technologies and on creating the appropriate framework for the private sector to undertake market-oriented research and development. A comprehensive study[23] recently conducted on behalf of the Commission of the European Communities examined the current state of industrial and materials technologies, their basic technological needs and development trends within the EC. The results indicate that industrial and materials technologies, their basic technological needs and development trends within the EC. The results indicate that industrial materials technologies are of paramount technological and economic importance for the EC and can support industrial competitiveness through the application of new materials, advanced design and manufacturing routes and high-quality strategies.

The EC New Industrial and Materials Technologies Programme for 1991-1992 is presented in box 3, and the BRITE/EURAM Programme for 1989-1992 is summarized in box 4.

On 23 April 1990, a Council Decision was made on the third framework programme of Community activities in the field of research and technological development (1990 to 1994). Following this, a common position on the specific research and technological development programme in the field of industrial and materials technologies (1991 to 1994) was agreed to on 6 May 1991. A final decision on this programme will be made by the Council only after the second meeting of the European Parliament.

C. Japan and South-East Asia

1. *Regional and industrial restructuring and the role of advanced materials*

The rising importance of advanced materials in the process of industrial restructuring in Japan and South-East Asia has been examined elsewhere in some detail.[24] The analysis confirms the view that scientific and technological development in the field of materials must be integrated into the far-reaching transformation under way in world industry. Ever since the first oil shock in 1973, industry has been restructuring towards sophisticated high-value-added

[23] Professor Horst Czichos in cooperation with R. Helms and J. Lexow, *Industrial and Materials Technologies: Research and Development Trends and Needs*, BAM, Berlin, 1991, Forschungsbericht 181.

[24] L. Kaounides, "Advanced Materials and Industrial Restructuring in Japan and South-East Asia 1980s-1990s", a paper presented at the Expert Group Meeting on Materials Policy Issues, Bangalore, India, December 1991. See also L. Kaounides, Final Report, EGM, Materials Policy Issues, Bangalore, India, UNIDO, July 1992.

products and manufacturing processes. At the same time, new methods of organizing production, such as JIT and TQC (total quality control), and new, flexible production technologies (CAD/CAM, FMS [flexible manufacturing systems], CIM [computer-integrated manufacturing] are diffusing in the manufacturing industry, partly in response to new market conditions. Markets have become global, characterized by an intensification of competitive pressures, faster product renewal, and high-quality, technologically sophisticated, customized products aimed at specific niches of an increasingly fragmented and differentiated world market. It is under these new circumstances that industry from the ESCWA region must compete in the 1990s and the implications of the development and application of new materials identified. Materials strategy is thus inseparable from overall industrial strategy and efforts to incorporate new materials not only into leading-edge technologies but also into product and process design throughout the manufacturing industry.[25] Acquisition and build-up of scientific and engineering capabilities in new materials must therefore take into account: (a) materials processing and fabrication technologies; (b) the channels and mechanisms for the effective transition of new materials R&D into the productive sphere and commercial application; (c) the needs of user industries and of the market as driving forces for materials development; and (d) the mechanisms for integrating materials and product design between suppliers and users in the context of world-class manufacturing (WCM). After all, it is in the context of the coercive forces imposed by the world market that firms and industries in such countries as the Republic of Korea, Taiwan Province of China, Brazil, Mexico, India, Nigeria and the ESCWA region must increasingly compete.

With the acquisition of higher labour skills and the inexorable rise in real wages in the NIEs of South-East Asia, the path of export-oriented industrialization (EOI) of the 1970s and 1980s, which is based on the simple formula of combining cheap labour with foreign technology acquisition and licensing, is now facing serious constraints. Industry is shifting to higher-value-added and more technologically sophisticated products and industrial processes. However, many firms in the region, in their attempt to move toward more sophisticated, higher-value-added activities and compete in the world market, have been hampered by the lack of critical raw materials, pure powders, components and parts as well as by the lack of in-house expertise and resources for R&D, and, importantly, in engineering design. Both engineering design and pure and applied research were badly neglected during the earlier labour-intensive phase of industrialization, and this is proving a serious handicap in countries such as the Republic of Korea and Taiwan Province of China. Major efforts are under way to correct for this. Design skills and R&D capabilities are a critical component of industrialization strategies in the 1990s, an area to which ESCWA member countries must pay special attention.

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[25] L. Kaounides, "Advanced Materials in World Class Manufacturing: The next source of competitive advantage", a paper to be presented at the British Academy of Management Conference, *Management into the 21st Century*, September 1992. The incorporation of new materials early on in the design of products and processes confers superior functional performance characteristics, higher quality and total system cost advantages through new conceptualizations and redesign of product and associated manufacturing and assembly processes. This is called materials-based simultaneous manufacture (MSM).

Box 2. United States national critical technologies

Materials

Materials synthesis and processing
Electronic and photonic materials
Ceramics
Composites
High-performance metals and alloys

Manufacturing

Flexible computer integrated manufacturing
Intelligent processing equipment
Micro- and nanofabrication
Systems management technologies

Information and communications

Software
Micro-electronics and opto-electronics
High-performance computing and networking
High-definition imaging and displays
Sensors and signal processing
Data storage and peripherals
Computer simulation and modelling

Biotechnologies and life sciences

Applied molecular biology
Medical technology

Aeronautics and surface transportation

Aeronautics
Surface transportation technologies

Energy and environment

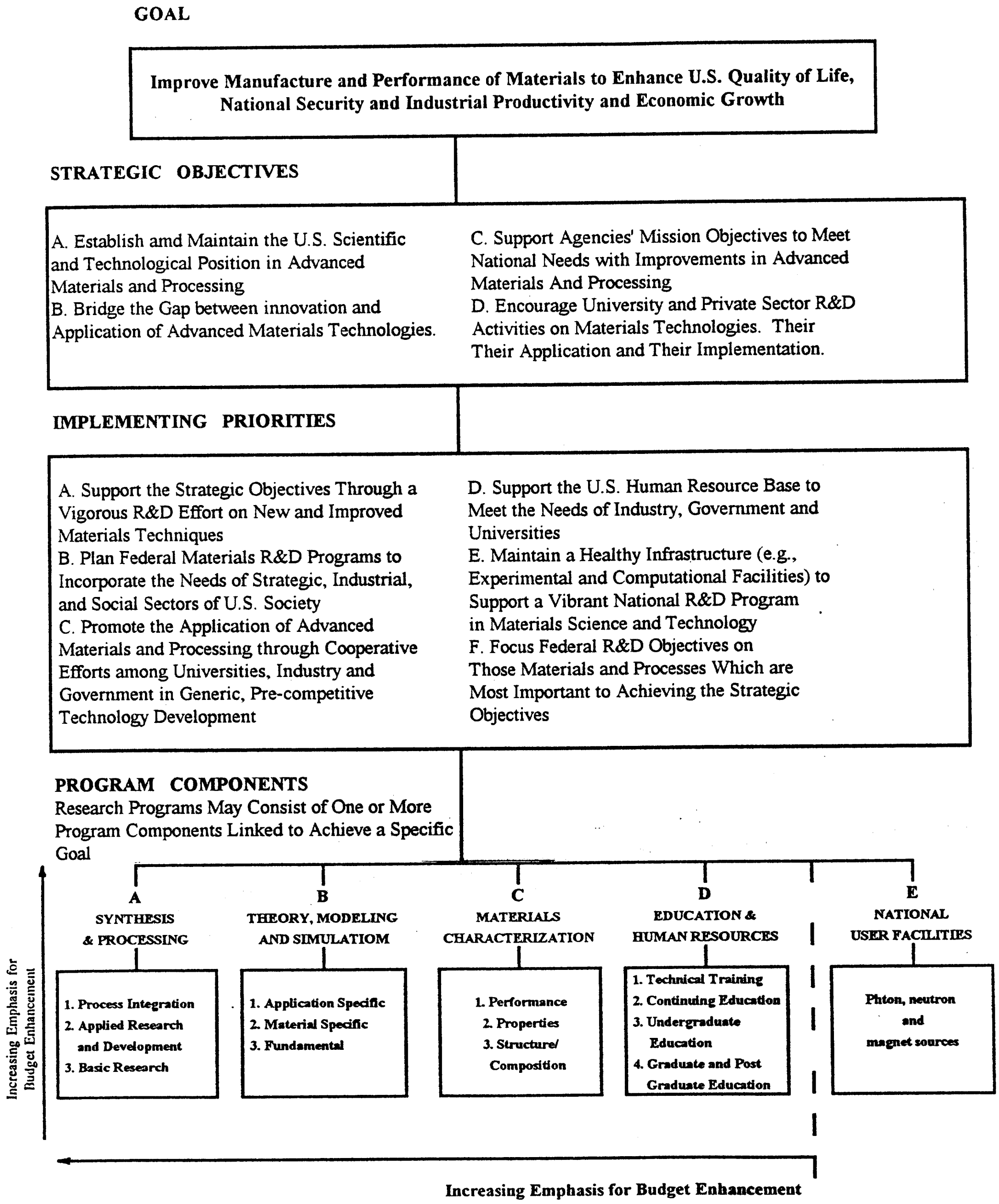
Energy technologies
Pollution minimization, remediation, and waste management

Table 11. United States advanced materials and processing programme R&D funding by research component

Component	FY 1991 $M	FY 1991 %	FY 1992 $M	FY 1992 %	FY 1993 $M	FY 1993 %	FY 1993 Growth over FY 1992 ($M)
Synthesis and processing	670.1	40.3	682.9	41.2	747.7	41.0	64.8
Theory, modelling, simulation	219.1	13.2	223.6	13.5	253.3	13.9	29.7
Materials characterization	481.2	28.9	473.8	28.6	503.0	27.6	29.2
Education/human resources	19.1	1.2	21.1	1.3	26.9	1.5	5.8
National user facilities/other	273.8	16.4	257.2	15.5	290.5	15.9	33.3
Total component funding	1 663.4	100.0	1 658.6	100.0	1 821.4	100.0	162.8

Source: United States, Executive Office of the President, Office of Science and Technology Policy, Federal Coordinating Council for Science, Engineering and Technoloyg (FCCSET), Committee on Industry and Technology, "Advanced Materials and Processing: The Fiscal Year 1993 Programme".

Figure 34. United States advanced materials and processing programme (AMPP)



Source: United States, Executive Office of the President, Office of Science and Technology Policy, Federal Coordinating Council for Science, Engineering and Technoloyg (FCCSET), Committee on Industry and Technology, "Advanced Materials and Processing: The Fiscal Year 1993 Programme".

Box 3. New industrial and materials technologies programme of the EC for 1991-1992

AREA I: MATERIALS—RAW MATERIALS

Raw materials:
Exploration technology; mining technology, mineral processing.

Recycling:
Technology for recycling and recovery of industrial waste including non-ferrous metals; recycling, recovery and reuse of advanced materials.

Structural materials:
Metals and metal matrix composites; ceramics, ceramic matrix composites and advanced glasses; polymers and polymer matrix composites.

Functional materials for magnetic, superconducting, optical, electrical and biomaterial applications:
Magnetic materials; high temperature superconducting materials; electrical and ionic conducting materials; optical materials; biomaterials.

Mass commodity materials:
Packing materials; new construction industry materials.

AREA II: DESIGN AND MANUFACTURING

Design of products and processes:
Innovative tools and techniques; methodologies for complex components; maintainability and reliability.

Manufacturing:
Tools and techniques for high quality manufacturing; manufacturing techniques for industrial use of advanced materials; integrated approach to chemical and process engineering.

Engineering and management strategies for the whole product life cycle:
Design integrating strategies; engineering; human factors in engineering and manufacturing management.

AREA III: AERONAUTICS

Activity in aeronautical technology:
Environment related technologies; technologies of aircraft operation; aerodynamics and aerothermodynamics; aeronautical structures, and manufacturing technologies; avionic system technologies; mechanical, utility and actuation technologies.

(Continued)

For more information concerning Areas I and II please contact:

Commission of the European Communities
Directorate XII C (Brit/Euram)
rue de la Loi 300
B-1049 Brussels

Telephone (32 2) 235 23 45 Fax (32 2) 235 80 46

For more information concerning Area III please contact:

Commission of the European Communities
Directorate XII C (aeronautics)
rue de la Loi 200
B-1049 Brussels

Telephone (32 2) 235 08 07 Fax (32 2) 235 06 56

Source: Official Journal of the European Communities.

Box 4. Brite/Euram Programme, 1989-1992

Programme summary and objectives

Funds estimated as necessary for the execution of the programme amount to ECU 499.5 million (including 4.5% staff costs).

I. ADVANCED MATERIALS TECHNOLOGIES

The work in this area will focus on the development of improved or new materials and material processing for a wide range of possible applications except those directly related to information technology (IT) covered in Esprit* adopted by Decision 84/130/EEC.

1. Metallic materials and metallic matrix composites

Objectives: extended working life of components; higher operating temperatures for increased thermal efficiency; better and more effective material processing techniques.

2. Materials for magnetic, optical, electrical and superconductingapplications:

Objectives: improved materials and materials processing for optical magnetic, electrical and superconducting applications.

3. High temperature non-metallic materials

Objectives: design methodologies for products based on ceramics, glasses and amorphous materials; improved monolithic and ceramic composites and metal/ceramic interfaces for industrial applications; better processing techniques and quality control strategies.

(Continued)

4. <u>Polymers and organic matrix composites</u>

Objectives: development of polymers for specific applications; more cost effective process techniques for parts made from polymer and polymer matrix composites; design rules for the specification and manufacture of engineering polymers and composites; new polymers with improved recycling attributes; improved product assurance techniques.

5. <u>Materials for specialized applications</u>

Objectives: improved materials and their processing for specialized applications.

II. DESIGN METHODOLOGY AND ASSURANCE FOR PRODUCTS AND PROCESSES

The development of techniques to improve product quality and the reliability and maintainability of structures and manufacturing systems by clarification of the design aims for both product and process, and by refinement of the criteria against which the attributes are measured. The exploitation of materials for application in sensors, and the reduction in the whole life costs of sensors are also included in this section. This will complement work in Community IT programmes, where on-line control is treated, including monitoring and diagnostics, predictive maintenance and quality assurance.

1. <u>Quality, reliability and maintainability in industry</u>

Objectives: improved performance measurement for manufacturing operations in a wide variety of industries; improved and more predictable physical and environmental behaviour of products; improved quality control strategies; design rules foı reliability and maintainability of components, structures and systems including machinery operating under varying conditions.

2. <u>Process and product assurance</u>

Objectives: reduction of while life costs of sensor systems for process control; exploitation of materials properties for applications in sensors; use of advanced measurement techniques for more cost-effective examination of topology; improved energy control for industrial applications, improved non-destructive testing methods for product assurance.

III. APPLICATIONS OF MANUFACTURING TECHNOLOGIES

Here the task is to identify and address the needs of manufacturing industry and particularly the less advanced sectors, many of which have a major part made up of SMEs. It is to be expected that modelling of physical processes will be a valuable instrument for progress. Also addressed is the challenge to the industries based on the use of flexible materials. The work will mainly focus on product and process development, transferring and adapting technology already used in other sectors. This should complement work in Esprit where IT systems for advanced manufacturing and CIM are being developed.

(Continued)

1. Advancing manufacturing practices

Objectives: identifying means for improving manufacturing practices in specific sectors; transfer and adaptation of technology already used in other sectors.

2. Manufacturing process for flexible materials

Objectives: increased process flexibility; reduced waste of material; improved process and product quality.

IV. TECHNOLOGIES FOR MANUFACTURING PROCESSES

Improved techniques for shaping, joining and assembly, surface treatment, chemical processes and particle technology are fundamental needs for industry. Advancement of these processes is essential for securing manufacturing competitiveness.

1. Surface techniques

Objectives: cost-effective surface treatments for industrial applications; techniques for quality assurance and control of the treatment process.

2. Shaping, assembly and joining

Objectives: improved methodologies for shaping processes and assembly, improved joining techniques to improve reliability and reduce defect levels; methods for testing welded and bonded joints to improve reliability of results and service predictability; design methodology for joining; better understanding of beam/workpiece interactions for industrial power beam processes.

3. Chemical processes

Objectives: improved predictability and yield in chemical processes; membrane materials with improved characteristics; improved performance of membrane processes; new systems for separation in hostile environments.

4. Particle and powder processes

Objectives: improved techniques for particle production to optimise produce shape, structure and stability; cost-effective techniques for particle categorization and process performance; better approaches to handling and separation; cost-effective routes for small lots of high quality powder.

V. SPECIFIC ACTIVITIES RELATING TO AERONAUTICS

This section covers precompetitive research in technological areas which are of primary relevance to aeronautics (in particular aeroplanes and helicopters) and are not yet covered in other programme areas.

(Continued)

1. Aerodynamics

Objectives: analysis and optimization of configurations for supersonic aircraft, including an estimation of aerothermodynamics heat loads; investigation of laminar flow technology; development of numerical methods; integration of computerized design technologies.

2. Acoustics

Objectives: noise source identification, prediction and reduction; basic investigation of acoustic fatigue and related damage tolerance on advanced composites; investigation of different construction methods; development and application of simulation models for response calculations under selected acoustic loads.

3. Airborne systems and equipment

Objectives: integration and operation of modern systems and equipment and corresponding new architectures; investigations concerning the use of onboard intelligent knowledge based systems (IKBS); investigations into the concept of the "All Electric Aircraft".

4. Propulsion system

Objectives: integration of advanced propeller and propeller-rotor system; provision of mathematical models for different design evaluation; specification and design of wind tunnel models and their components; specific aspects of air-breathing engine combustion.

* Development of materials under ESPRIT include: magnetic, magneto-optical, optical thin films for sensors, recording media and heads, optical layers and specific materials for opto-electronics, ceramics and polymers for IC packaging and specific substrates, superconducting thin films for low current applications and devices.

Access to critical technologies, parts and components from abroad for a range of sophisticated industries is proving either impossible or very expensive. It has therefore become obvious that the restructuring and the transition to high-technology activities necessitate the acquisition of a minimum amount of domestic materials-synthesis and processing capabilities. Consequently, considerable emphasis has been placed in both the Republic of Korea and Taiwan Province of China on the need to increase national materials-synthesis and processing skills. As these competencies grow, it becomes easier to attract, access and absorb technologies from abroad. It must be noted, though, that while total external dependence or reliance on foreign parts and components is tantamount to economic suicide, total self-reliance on materials science and engineering is neither possible nor desirable at the level of the firm, the industry or the economy in today's technological circumstances. Hence, internal or in-house competence-building, external mechanisms via inter-firm, cross-border alliances and technology flows, and access to a fast-changing global pool of scientific knowledge go hand in hand. Policies to promote domestic competence in materials-related fields are influenced to a considerable degree by a range of other domestic policies, such as the degree of liberalization, protection of intellectual property rights, merger and acquisition policies, and open-door policies to foreign investment and technology flows. Advanced materials comprise the majority of the ten national projects[26] identified in 1990 as urgent priorities to be supported and promoted by the Government of the Republic of Korea.

A similar, strategic emphasis on over ten critical high-technology sectors has emerged in Taiwan Province of China. On the other hand, the small size and nature of Singapore's economy has necessitated that emphasis be placed on advanced materials applications rather than development, and the provision of support services for companies in the aerospace and micro-electronics sector. Singapore's Government is encouraging large multinational corporations in electronics and chemicals to set up local R&D and design centres in the context of a long-run strategic objective envisaging Singapore as a major international centre for scientific and technological excellence. In the new Strategic Economic Plan prepared by the Economic Planning Committee of the Ministry of Trade and Industry, the aim is for Singapore to achieve the goal of becoming a developed nation by the year 2030. In the process, it plans to double annual expenditure on R&D from 1% of GNP in 1990 to 2% of GNP by 1995, compared to 1.8% of GNP in the Republic of Korea and 1.3% of GNP in Taiwan Province of China. The Government is to allocate up to $2 billion to an R&D fund, the aim of which is to develop skills, manpower and technologies specific to industry needs. In addition, 200 foreign research scientists and engineers are to be recruited annually over a five-year period. The recruitment is to be undertaken by the newly formed National Science and Technology Board (NSTB) whose function is to promote industry-driven R&D. The NSTB will encourage more private sector R&D through tax incentives and allowances and strengthen the technological and manpower base of Singapore by building several world-class research facilities and associated institutions and physical infrastructure, at the Science Park. The strategic objectives of some major chemical companies locating in Singapore are given in table 12.

The development and application of new materials by national and foreign firms rely on extreme environment, complex instrumentation, measurement and characterization technologies provided by very well equipped and manned research institutes already in place in Singapore (SISIR), Taiwan Province of China (ITRI) and the Republic of Korea (KSRI [see box 5]). Such institutes are acquiring a pivotal role in the industrialization strategies of these economies in the 1990s.[27]

The restructuring of industry in Japan and the first-tier NIEs has opened up opportunities for the rise of resource-based and labour-intensive activities in second-tier NIEs such as Malaysia and Thailand, and the economies of Indonesia, the Philippines, China and Vietnam. Many firms from Japan, the Republic of Korea, the Taiwan Province of China and Singapore are withdrawing from their high-wage locations and relocating plants and unskilled segments of the production process to the low-cost countries of the region. What seems to be emerging, therefore, is a very complex division of labour in which firms retain high-skill, critical component production and segments of the assembly process within Japan, while

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[26] These have now been incorporated into the "Highly Advanced National Project" launched in 1992. Advanced materials R&D areas were announced in August 1992.

[27] Note here the efforts of UNIDO to promote the establishment of international centres of excellence in the area, notably a major new initiative based in KSRI, Republic of Korea.

relocating other segments and sub-assemblies to first- and second-tier NIEs and other labour-abundant, low-wage economies in the region. Nevertheless, as the productive forces, skills, wages, and markets are growing in several first-tier NIEs, direct foreign investment of greater sophistication is encouraged in order to meet domestic demand in consumer durables and certain high-performance materials such as chemicals and metal specialties and engineering polymers. The need for higher-quality and high-performance materials is therefore being felt increasingly in the region in response to changing demand and locational patterns in user industries, as in electronics and automobiles.

As industry restructures globally, the new materials and manufacturing environment begins to exert pressure for the articulate materials strategies and responses by both private- and public-sector institutions in countries at very different stages of development and with shifting positions in the evolving regional and international division of labour. Clearly the early determination and implementation of what is feasible and desirable from the point of view of materials development and utilization in a particular economy is critical in today's fast-changing scientific and technological circumstances. There are cumulative gains from learning by producing and/or using, while severe penalties await late entry, which may in fact become impossible in some areas. Japan understood the importance of new materials very early on and has had long-run strategies in place since the early 1980s. The Republic of Korea and the Taiwan Province of China, drawing upon a large pool of domestic scientific capabilities, have laid considerable emphasis in recent years on the acquisition of advanced materials capabilities. Below is a brief look at the strategic orientation and mechanisms of implementation in each of the three economies, starting with Japan.

2. *Japan*

Micro-electronics, new materials and biotechnologies are the three leading-edge technologies identified in the early 1980s as providing the foundations for the rejuvenation of maturing branches of the industrial structure. They have also given birth to a whole new array of high-tech industries which are pulling the economy into the next century (see figure 37 and table 13). The promotion of new-materials development and use forms an integral part of a long-run strategic approach to reorient Japanese industry towards high-technology and knowledge-intensive production. The role of new materials in underpinning both technical change in all leading-edge technologies as well as conferring competitive superiority in manufacturing industry is very clearly recognized in both the private and public sectors. Advanced materials are therefore seen as having strategic significance for a successful reorientation towards high technology and the attainment of competitive superiority in the world market. Hundreds of Japanese companies entered new materials in the mid-1980s, and the emphasis in recent years has been on the commercialization of materials already developed and related to existing technical strengths of the companies concerned.

The Japanese Government[28] plays an important role in formulating science and technology policy. There are four institutions responsible for the formation and implementation of science and technology policy. These are:

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[28] "The Science and Technology Resources of Japan: A Comparison with the United States", United States National Science Foundation, NSF 1988-318.

Table 12. Major foreign companies in Singapore

Company	Ishihara Sangyo	Exxon Chemicals	Glaxo	DuPont
Project	$150m investment to manufacture titanium dioxide	$100m investment to manufacture oil additives and solvents	$100m investment to manufacture peptic ulcer drug Zantac; $100m plant for the process development and manufacture of new chemical entities	$150m investment to manufacture Polyacetal (1st phase: $25m compounding plant); $200m adipic acid project
Strategy	To establish a manufacturing plant to supply growing market using enriched raw material obtained from Australia	To establish a total business base to manufacture, market and distribute its products in the Asia/Pacific region	To establish world scale plant in low risk and highly efficient location to manufacture new drug for world market	To establish an Engineering Polymer Centre to better service its clients in the Asia/Pacific region by shortening the supply chain
Key features	- Ishihara's first offshore plant - Ishihara's largest plant - Raw materials from Australia - Supply growing markets	- Very significant chemical operation integrated with its refinery operation - R&D laboratory on fuel technology - Marketing, sales and technical capability	- Biggest selling drug in the world - Profit maximization - Provided funds for another Zantac plant other R&D programmes	- Important sourcing point for DuPont's global engineering polymers business - Technical support and product development centre to meet needs of Asia/Pacific clients - Regional headquarters for its electronics, agricultural products and polymers businesses

Source: Economic Development Board, Singapore, 1990.

Box 5. The Korea Standards Research Institute

HISTORY:

- December 1975: The Korea Standards Research Institute (KSRI) was established as the central authority of the national standards system.

- September 1976: Groundbreaking was held at the site in Taedok Science Town.

- March 1978: The first phase of construction was completed.

- July 1982: The Precision Instrumentation Centre was established.

- November 1984: The standard HF broadcasting station (HLA) began operation.

- October 1988: KSRI became members of the three consultative committees of CIPM, CCDM, CCT, and CCPR.

FUNCTIONS:

- Maintenance and international comparison of national measurement standards.

- R & D to improve measurement standards.

- Calibration of measurement standards and instruments.

- Development and provision of standard reference materials and standard reference data.

- Research and development of new measurement technology.

- Development of methods for applying this technology.

- Training and consultation on measurement technologies.

- Development and repair of high-precision instruments.

DEVELOPMENT AND APPLICATIONS:

The development and application of new materials relies on a set of basic technologies.

(Continued)

Technologies for beam generation	Extreme environment generation	Analysis and evaluation
Microlithography, annealing, milling elimination of defects in ceramics, surface quality improvements of organic conducting materials. Electromagnetic waves: gamma rays, X-rays, ultraviolet rays. Particle beams, electrons, positrons, neutrons, protons, atoms, ions.	These technologies are indispensable for studying new phenomena, creating new materials precision measurements and extreme environments, and analysis/evaluation of new materials.	Essential for the creation, application and quality assurance of new materials.

The KSRI therefore conducts research on: Precision-measurement technology, advanced precision instruments, extreme environment generation technologies, ultra-low, ultra-high temperature, ultra-high pressure, ultra-high vacuum and ultra-clean room environments, and beam-generation technology for new materials analysis.

In analysis/evaluation technologies research is conducted on:

(a) Evaluation of materials strength at 4.2k;
(b) Characterization of piezoelectric materials;
(c) Characterization of Si-steel;
(d) Analysis of inorganic materials at ppb level with GD-MS.

Given the increasing demand from research institutes and industries for evaluation technologies, the development of new materials evaluation technologies by KSRI is a national project.

Efforts are also made to standardize new materials characterization and testing procedures across countries: Recognition that standards require international coordination and cooperation to facilitate industrial application and trade.

(Continued)

KSRI: Manpower

Classifications	Employed	Remarks
Top management (President, Auditor)	2	
Research	200	
Engineering	66	
Technician	130	Senior staff with PhD degree: 89
Administrative	68	
Others	20	
Total	486	

By academic major and degree

Major/Degree	PhD	MSc	BSc	Others	Total
Physics	35	38	9	-	82
Chemistry	12	11	2	1	26
Mechanical Engineering	12	17	10	20	59
Electrical Engineering	3	1	1	16	21
Electronic Engineering	2	15	39	19	75
Chemical Engineering	4	2	10	2	18
Computer Science	-	2	4	4	10
Metallurgical and Materials Engineering	15	6	4	-	25
Nuclear Engineering	1	5	1	-	7
Industrial Engineering	2	1	3	-	6
Politics and Law	-	-	5	-	5
Business Management, Administration, Economics	2	8	19	1	30
Others	1	4	17	100	122
Total	89	110	124	163	486

(Continued)

Plan for a materials evaluation centre (KSRI)

Purposes: Promotion of development and practical application of new materials through the development of materials characterization technology, the standardization of materials evaluation methods, and the operation of a materials data bank.

History:

October 1987 "A Plan of New Materials Characterization Centre", was presented at the 7th R&D seminar of KSRI.

August 1988 "Feasibility Study on the Development of Characterization Technology for Advanced Materials", was conducted by KSRI under the financial support of MOST.

January 1990 The Minister of MOST approved the establishment of Materials Evaluation Centre at KSRI.

KSRI plans to establish the Materials Evaluation Centre in May 1990.

Functions: Research and development: Basic research on new principles/new phenomena. Development of characterization technology. Development of techniques and equipments for materials evaluation.

Standardization: Research on the standardization of materials evaluation methods. Organization of an inter-laboratory cooperation system for testing and analysis. Promotion of international collaboration and joint research.

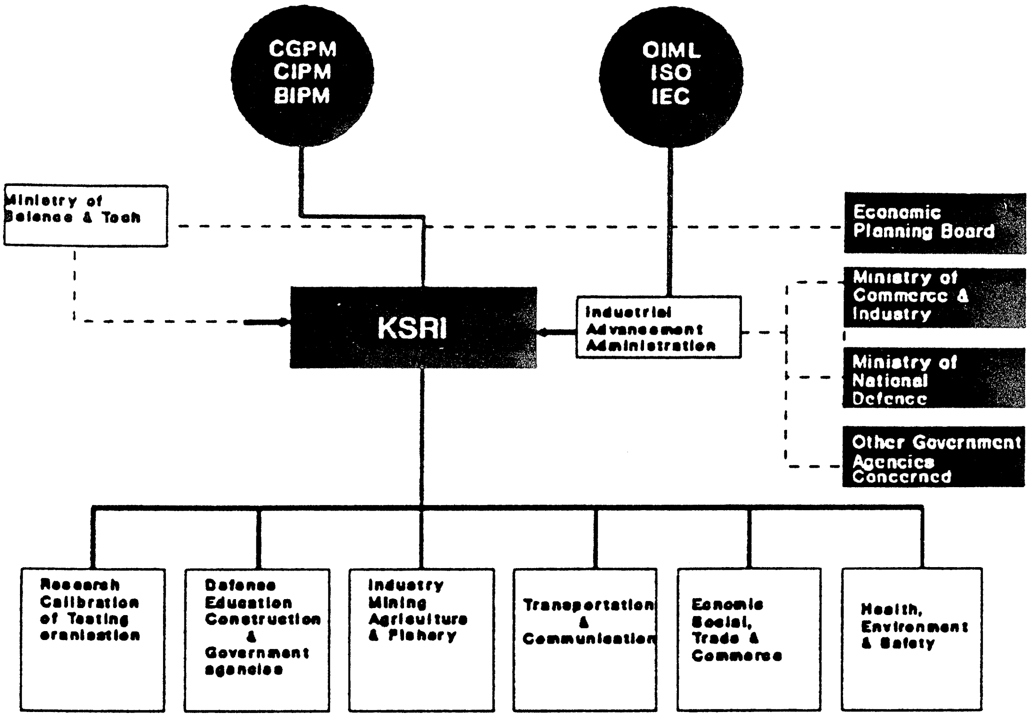
Service: Materials evaluation service. Operations of materials data bank.

GOALS

1st Phase: 1990-1991 Establishment and operation of materials evaluation centre	2nd Phase: 1991-1996 Development of high technology for materials evaluation	3rd Phase: 1997-2001 Creation of new evaluation technology
* Participation in national research projects for materials characterization * Organization of inter-laboratory cooperation system (domestic) * Construction of data bank * Promotion of international joint research and cooperation	* Enhancement of research capacity to the level of advanced countries * Expansion of database * Participation in international standardization projects * Foundation of international organization for materials evaluation in Asia/Pacific region	* Application of new principles and new phenomena for the development of new evaluation technologies * Transfer of new materials evaluation technology to developing countries * Exchange of databases with foreign countries

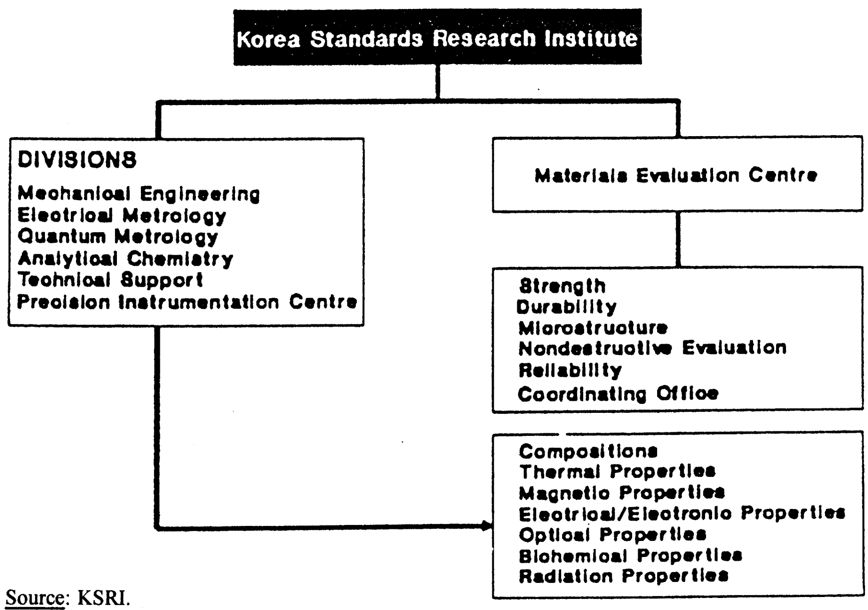
Source: KSRI.

Figure 35. National Standards System (NSS)



Source: KSRI.

Figure 36. Organization of Materials Evaluation Centre



Source: KSRI.

(a) Prime Minister's Council for Science and Technology (CST) is the foremost institution in Japan in this area, recommending long-term policy objectives. Key recommendations to the Prime Minister are of critical importance to the future direction of science and technology;

(b) The Science and Technology Agency (STA) provides research and planning input for the Council. Amongst its major responsibilities are the management and undertaking of science and technology activities in basic research and advanced fields of science. Work is carried out at research institutes attached to the Agency and semi-autonomous public organizations (e.g., RIKEN). The Japan Research and Development Corporation (JRDC) has the function of encouraging the commercialization of promising R&D at universities and research institutions;

(c) The Ministry of Education, Science and Culture (MONBUSHO) accounts for nearly half the R&D budget of ministries and agencies in all areas of science and technology;

(d) Ministry of International Trade and Industry (MITI) plays a central role in the formation and implementation of industrial policy but is also active in the promotion of industrial R&D. Within MITI, the Agency for Industrial Science and Technology (AIST) sponsors a number of projects which aim to develop technologies with potential commercial value, and research is carried out mostly in 16 national and regional industrial research centres administered by AIST.

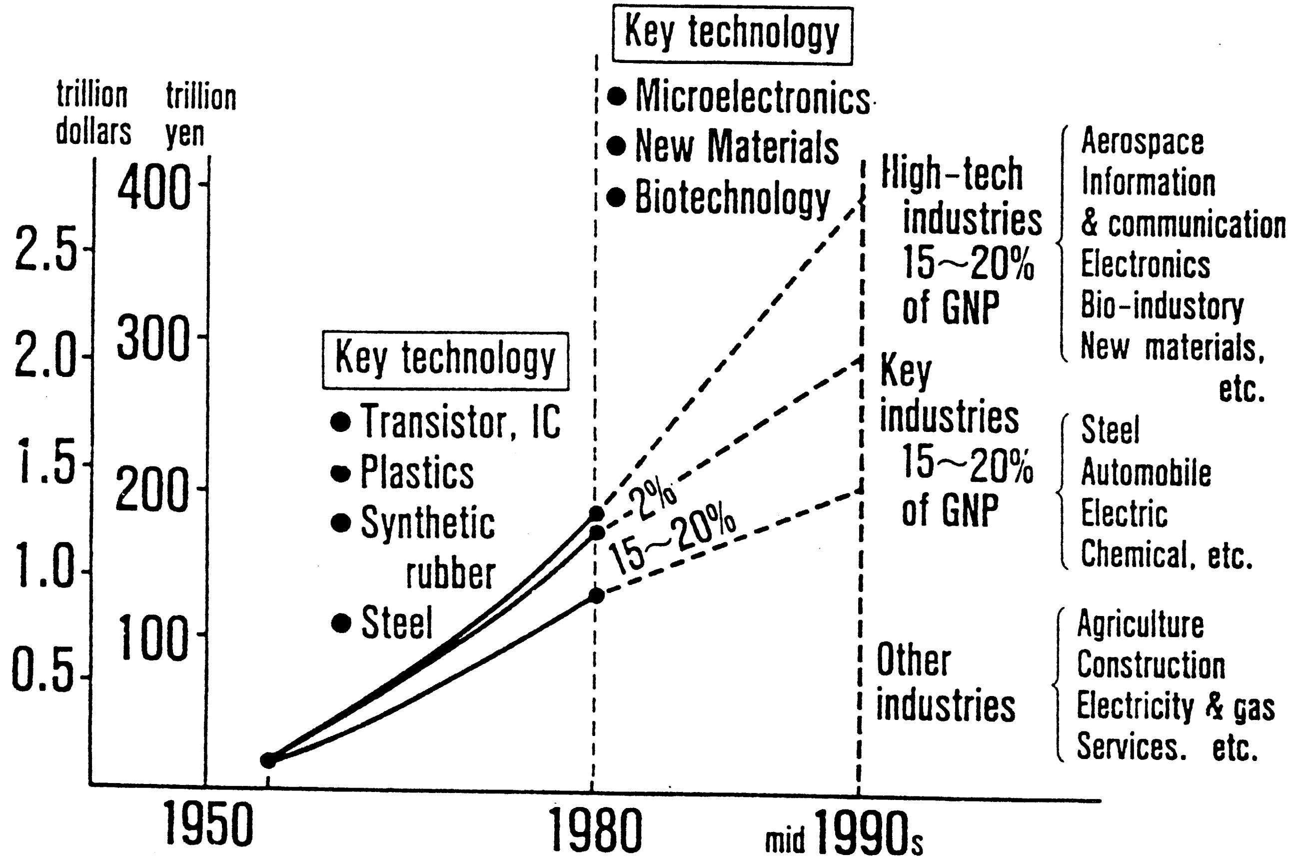
The CST formulated a government R&D plan for materials science and technology in October 1987. R&D in the field of advanced materials is mainly the responsibility of three ministries, namely MONBUSHO, MITI and STA. MITI's policy is coordinated by the New Materials Policy Office set up in 1984 and is carried out by AIST. MITI's Fine Ceramics Office coordinates policy on fine ceramics. STA's policy on new materials concentrates on the undertaking of basic research, mainly through RIKEN, the national research institutions at Tsukuba Science City and the JRDC.

There are two major groups of MITI long-term R&D programmes, both of which attach great importance to new materials. The majority of projects under the "R&D Project on Basic Technologies for Future Industries" relate to new materials, as shown in table 14.

There are a large number of research projects on new materials in the public sector coordinated by MITI and STA. Although there is a measure of coordination between new-materials policy and the role of the public and private sector, within and between MITI, STA and MONBUSHO, it is informal and not entirely satisfactory, according to officials. Nevertheless, the approach is systematic, comprehensive and long-term.

Figure 37. High growth industry In Japan

Outlook on Japanese industrial structure



Source: Japan Techno-Economics Society.

Table 13. Reaching toward high levels in industry (Japan)

	Textiles	Petrochemicals	Steel	Electrical home appliance	Automobiles
Creating higher added value	Cresting products with high added value (mixed yarns, yarns with irregular cross sections, conjugated yarns, ultrafine weaves) strengthening of downstream departments.	Elimination of general purpose products, addicting of high level functions (development of fine chemicals). (Engineering plastics, fibre-reinforced plastics and alloys).	Creating high-performance and high-class products (making of fine steel). Magnetized steel sheet. stainless steel.	Move to large-model appliances (large-model colour television, large-model refrigerators). Providing high performance and multiple functions. (Hi-Fi VTRs, VTRs integrated with cameras, S-VHS video, multi-function microwave ovens. Televisions with built-in BS tuners. Convertible disc players) Digitalization DAT, electronic still cameras). Widespread use of electronics in home appliances.	move to larger models. Higher class, greater sophistication (DOHC engines, 4WD, 4WS Customization. Addition of information-processing function.
Improvement of production processes	Introduction of information and production systems. Shortening the cycle of production plans. Introduction of air jets and water jets.	High-level processing technologies, quality control.	Establishment of comprehensive production systems. Introduction of AI (Artificial Intelligence).	Multiple-type small-lot production systems.	Multiple-type small-lot production systems. Ultra automated assembly lines. On-line parts ordering systems. Introduction of CAD/CAM.
Technological development	High-efficiency polymerization. Ultra-high-speed spinning. Automatic sewing systems. Superfibres.	Development of empura, etc. and expansion into leading-edge fields.	Fusion reduction steelmaking. Semi-solidified machining processes. Full-scale introduction of AI in all processes.	Hi-vision, AI, super-conductivity.	Car electronics. Ceramic engines. Development and use of new materials.
Diversification	Synthetic resins, films. Artificial leather, carbon fibres. Electronic instruments for medical treatment. Pharmaceuticals, biotechnology. Housing, construction materials.	New materials, pharmaceuticals, biotechnology. Electronic parts, housing, construction materials.		Information-related services, semiconductors, software field.	Information-related services. Micro-electronics. Aeronautics and space. Sports clubs, restaurants. Housing.
Other				Construction of VANs for electronic home appliances.	Setting up of dealership networks.

Source: Agency of Industrial Science and Technology (AIST), MITI.

Figure 38. Administrative structures of science and technology in Japan, 1987

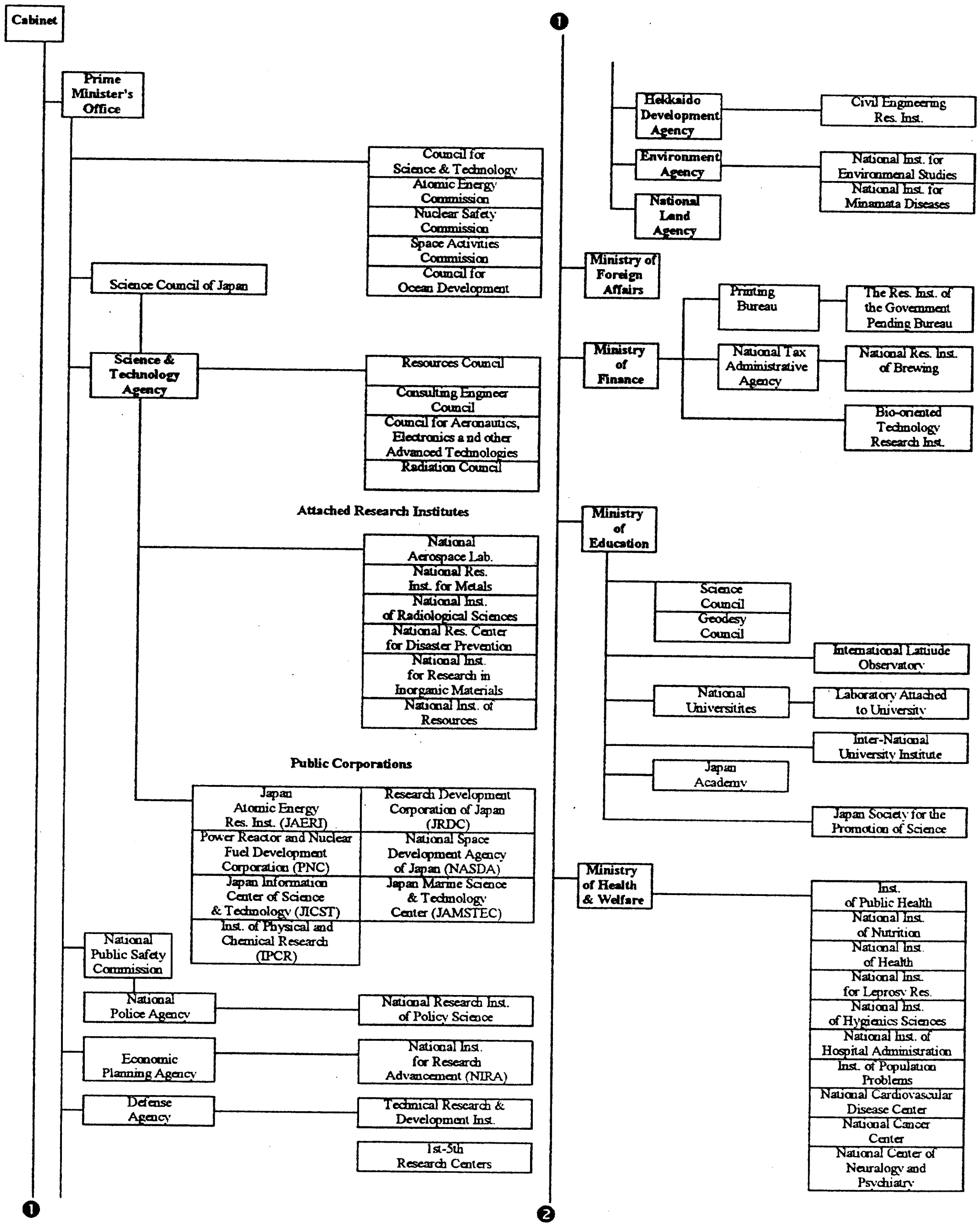
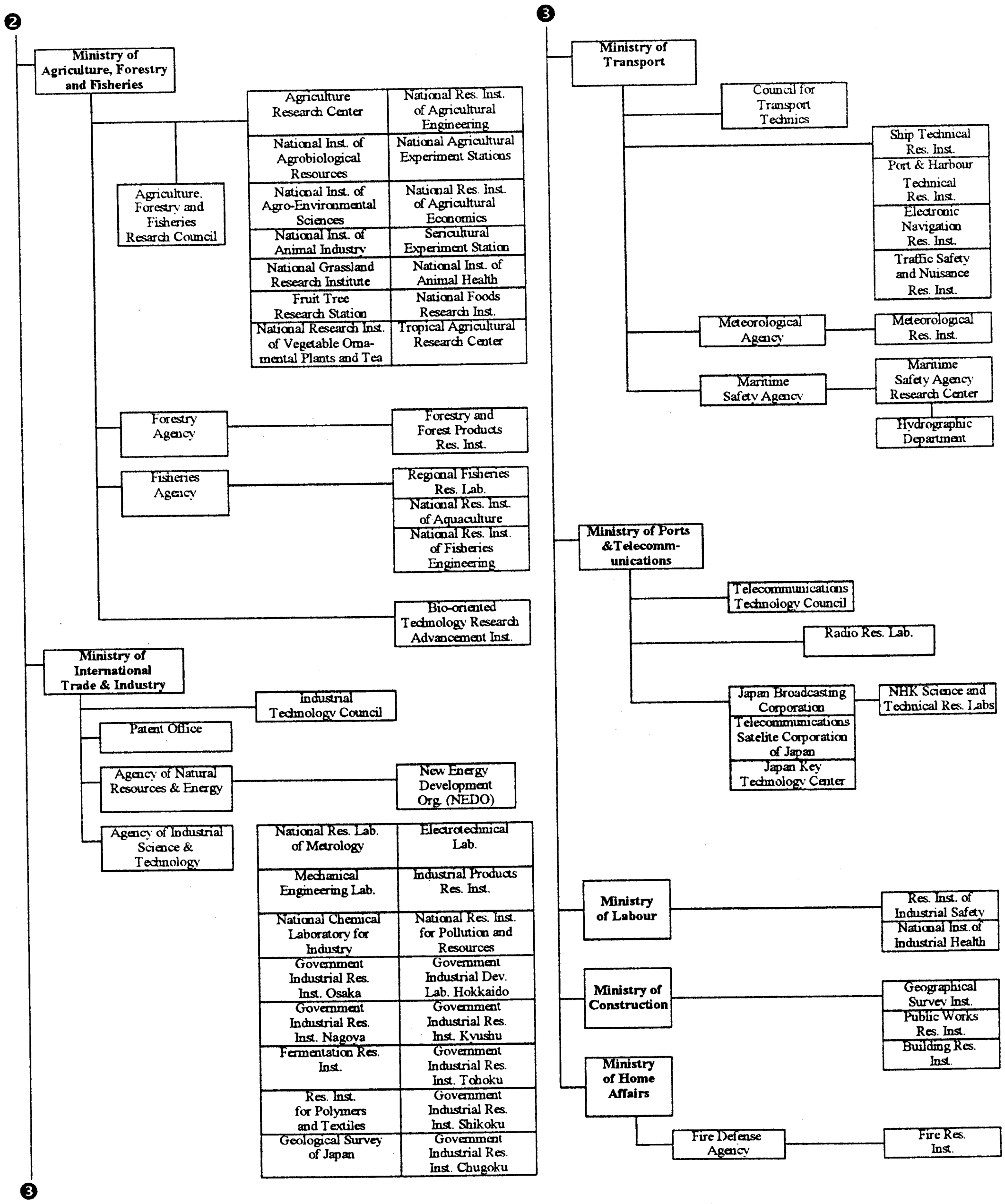


Figure 38. (*continued*)



Source: Japan Science and Technology Agency.

3. *The Republic of Korea*

In early 1992, the Government of the Republic of Korea launched the "Highly Advanced National Project", widely known as the G7 Project, aimed at bringing the country's scientific and technological capabilities to the level of the G7 group of nations by the year 2000 (see table 15). The Government, faced with inflation, rapidly rising labour costs and a large trade deficit, is keen to promote a shift towards high-value-added, high-technology products and industrial processes. Thus, it hopes to establish the Republic of Korea as a major scientific and technological power able to challenge Japan and Western nations by the early 21st century. To achieve this, indigenous capabilities in a range of high technologies are deemed essential, and the Government, through the science and technology ministries, is therefore planning to spend more than $3 billion over the next 10 years, with matching funds from private industry.[29] The Project supports seven major technologies which are near the market, namely next-generation integrated semi-conductors (256-megabyte RAM by 1996 and 1-gigabit by 2000), an area of existing expertise in the Republic of Korea, Integrated Services and Data Network, High-Definition Television (HDTV), the electric vehicle, intelligent computers, antibiotics and chemicals for agriculture, and advanced manufacturing systems. A second part of the project supports seven more fundamental or basic technologies, including advanced materials, next-generation transport systems and biotechnology.

<u>Advanced Materials R&D Group, Korean Institute of Science and Technology</u>

The Advanced Materials R&D Group was formed in 1989 at the Korean Institute of Science and Technology (KIST) which will utilize the Institute's considerable interdisciplinary capabilities in science, technology and research in order to achieve the aim of advanced materials as a significant national project in the 1990s. The development of advanced materials and related technologies is viewed as critically important in facilitating technical innovation in high-technology industries such as aerospace, telecommunications, genetic engineering, energy and transportation, as well as in raising productivity in existing industries and the economy at large. Given the demands of industry in the Republic of Korea, as well as of its economy, for advanced materials development, the existing strengths and resources of KIST, accumulated over a 20-year period, have been brought together with the creation of the Advanced Materials R&D Group. Apart from drawing upon its own fundamental science and technology base, the Group will also collaborate with industry, universities and other public research institutes, at home and abroad, in the field of advanced materials. Details of the structure and aims are given below.

The Advanced Materials Group at KIST in 1990 conducted a survey entitled "Prospects of Advanced Materials in Korea" under contract with MOST. The Group identified advanced materials as a national project the same year, and projects are under evaluation for further development in the 1990s. A new proposal has been submitted recently for an advanced materials development programme, based on market and technology demands which contain ten individual materials to be used in high-tech industry, and this is currently under evaluation by a special committee of MOST. In 1992, KIST was reorganized and the Advanced Materials

[29] In 1991, total science and technology R&D by Government and industry stood at approximately 2% of GNP and is expected to rise to 3.2% of GNP by 1996.

R&D Group transformed into the Advanced Materials Division. KIST will play a crucial and leading role in implementing the New Advanced Materials Project announced in mid-August 1992 by MOST, as part of the 14 projects under the "Highly Advanced National Project" for 1992-2000.

One half to three quarters of the research is to be undertaken by institutes affiliated with the Ministry of Science and Technology. The Korean Institute of Science and Technology (KIST)[30] moved from carrying out contract research for industry in the 1960s to conducting long-term research of importance to the national interest, and several new institutes have sprung from it. Much of the research on advanced-materials is to be conducted by KIST. The major materials research areas are under study at the moment, and the final plans on advanced-materials projects were announced in August 1992 (see table 16).

In order to serve the more immediate needs of industry, the Government of the Republic of Korea set up in 1989 the Korea Academy of Industrial Technology (KAITECH)[31] which reflected a shift away from simply emulating the United States approach to scientific research, namely the establishment of world-class research institutes. Rather, the lesson drawn from Japan was that emphasis on production engineering skills is required. KAITECH therefore promotes, funds and coordinates near-market research among Government, industry and the universities. KIST, its affiliated institutes and KAITECH will play an important role in implementing the HAN Project, which forms a first attempt by the Republic of Korea to coordinate the research activities of all science and technology related ministries and institutes concerned with science and technology. This will enable the avoidance of, amongst other things, overlaps in research efforts and other inadequacies of the research funding system.

4. *Taiwan Province of China*

Taiwan Province of China is very much aware that other economies in the region are restructuring towards high-value-added production. Government officials therefore emphasize the need for Taiwan Province of China to upgrade skills, restructure towards high-value-added, sophisticated production, and promote the advancement of science and technology through indigenous R&D and the acquisition of technology from abroad. In contrast to the Republic of Korea, however, industry in Taiwan Province of China is highly fragmented, containing a proliferation of many small firms which face serious difficulties in mastering the skills and obtaining resources necessary for effective R&D. The Industrial Technology Research Institute (ITRI), established 20 years ago, is the main R&D institute in Taiwan Province of China, and its task is to assist industry in technological upgrading. Given the current emphasis on high technology, ITRI has acquired even greater significance as a central mechanism for transmitting

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[30] In 1981, KIST merged with the Korean Advanced Institute of Science (KAIS), a graduate school of scientists and engineers and subsequently an important university producing over 700 graduate scientists and engineers per year, and formed KAIST (Korean Advanced Institute of Science and Technology). The two institutions were split again in 1989. See box 6.

[31] KAITECH provides 70% of funds, with interest-free loans for near-market research between university and industry scientists (e.g., HDTV), with the rest coming from private companies involved with research. See Nature, vol. 354, 21 November 1991.

science and technology R&D to private industry. In essence, its function today is to assist industry to restructure towards high technology. It is an institution of critical importance to the science and technology strategy of Taiwan Province of China, and a study of this strategy would be of much use to ESCWA member countries. Its role in disseminating new technologies in advanced materials is illustrated in figures 42, 43 and 44.

Taiwan Province of China aims to achieve the status of a fully industrialized economy by the year 2000, with the following strategic sectors at the forefront: Advanced materials, sophisticated consumer electronics, information systems, telecommunications, automation technologies, aerospace and environment technologies. Considerable effort has been expended in identifying the most promising technology areas, and foreign consultants have been brought in to set strategic objectives in all areas of high technology. The development targets for materials science and technology in Taiwan Province of China in the 1990s are shown in table 17. The key materials for the nine high-technology sectors selected for promotion this decade are shown in table 18.

The National Science Council or NSC is responsible for setting up national policy on science and technology through conferences, meetings, liaison with other government institutions, along the lines of the United States National Science Foundation. A major objective consists of attracting high technology to Taiwan Province of China, and the NSC decides what type of high technology will be relevant to the Science Park. An important consideration is to remedy the shortcomings in the undertaking of private R&D, with the aim of raising the share of private-sector R&D in total outlays to 60% by 1995. Moreover, five national labs have been set up to enhance basic scientific research in the 1990s. The NSC organizes the various research programmes and their allocation across research institutes and decides when programmes will eventually merge. For example, in opto-electronics, it decides (by consensus, meetings, and visits to industry) which research is to be undertaken at university labs, at ITRI and/or in private industry.

Materials technologies were identified by the NSC as having key importance as early as 1978. The recent emphasis on high-technology industries has added impetus to this area, as a high-technology sector *per se* and as the foundation for the promotion of materials-related technologies in the 1990s. The objectives of advanced-materials research are arrived at in collaboration with universities and ITRI. Advanced materials R&D spending in 1990 was third in importance out of total R&D spending, after information technologies and energy (given large import dependence on the latter). There exist considerable opportunities for the development of polymer-based advanced materials in Taiwan Province of China (see tables 19, 20 and 21). The establishment of a domestic base and key technologies will involve licensing, in-house R&D, cross-border strategic alliances, and the development of key technologies at ITRI's Materials Research Laboratories and Union Chemical Laboratories together with the Chung Shan Institute. These institutions can provide rich lessons for the economies of the ESCWA region.

Table 14. Outline of MITI activities related to new materials figure: budget for FY 1990

(Millions of yen)

		FY 1990	FY 1989
	A. Intensive governmental R&D projects on new materials		
1.	Under the budget for the R&D project on "Basic Technologies for Future Industries": R&D on new materials	20 153	(16 077)
	* Synthetic membranes for new separation technology	192	(358)
	* Electroconductive polymers	162	(295)
	* High-performance plastics	126	(235)
	* Photo-reactive materials	471	(318)
	* Non-linear electronics materials	540	(151)
	* High-performance ceramics	1 313	(1 149)
	* High-performance advanced materials for outer space	1 001	(301)
	Total (7 ongoing themes)		
	Under the R&D project on superconductive materials and devices: R&D on superconductivity		
	* Superconductive materials	1 618	(1 252)
2.	Other government-funded technological development related to new materials:		
	(a) Under the budget for the "Large-scale R&D" project:		
	* Processing and machining system for new materials	2 935	(2 329)
	* Advanced chemical-processing technology	29	(0)
	(b) Under the budget for the "Moonlight" project (R&D on energy conservation technology):		
	* Development of ceramic gas turbine for co-generation of electricity and heat	1 132	(707)
	* Application for superconductivity in the electricity supply system	2 610	(1 962)
	(c) Under the budget commissioned corroboration testing of light-water nuclear technology (inspection-free reactors):		
	* Materials for light-water nuclear reactors.	1 924	(1 866)
	(d) Research for the application of superconductivity in the electricity supply system, including energy storage.	150	(78)

Table 14. (*continued*)

	FY 1990	FY 1989
(e) Biodegradable plastics	53	(14)
(f) Unmanned experiment system for use in space (development of "Free Flier" experiment observation system)	5 242	(4 487)
(g) Special research at national laboratories:		
* 34 themes related to new materials	455	(413)
(h) R&D cooperation for composite satre holding substances in desert area	200	(161)
B. SUPPORT FOR PRIVATE R&D ACTIVITIES		
1. Improvement of R&D infrastructure; NEDO (New Energy Development Organization) will be reorganized and expanded to include new business as follows:		
(a) Establishment of experimental facilities		
* Ion engineering centre * Underground micro-gravity experimental centre * Laser application engineering centre * Ultra-high-temperature materials experimental centre		
(b) Subsidies for international R&D cooperation (theme must be related to the HumanPortion(Portion Frontier Science programme and/or material science).of 417of 401)		
2. Expansion of projects conducted by the JKTC (Japan Key Technology Centre)		
(a) Financing and loans: These are provided to the JKTC from the Government's industrial financing account so that the JKTC may expand its financing and loans to private corporations conducting R&D on new materials and other advanced or basic technologies.		
(b) Financing/loans from the Industrial Financing Special Account26,000(26,000)		

Table 14. *(continued)*

		FY 1990	FY 1989
3.	Under the grant scheme for petroleum exploration technologies (grant rate: 75%)		
	* Technology for the production of materials to be used under high-temperature corrosive conditions (Development of materials for structural components of oil production equipment.)	454	(980)
4.	The R&D Promotion Tax System for Basic Technologies		
	* System: Amount of tax deduction = 20% of increased testing/research expanse (A) + 7% of cost of basic technological R&D assets (B); Deduction ceiling: 15% of corporate tax amount (if (B)=0, 10% of corporate tax amount).		
	C. Promotion of practical application of new materials		
1.	Measures for basic new materials industries (studies and research)	6	(6)
2.	Studies and research for standardization of new materials		
	(a) Fine ceramics	30	(25)
	(b) Organic and composite new materials	12	(11)
	(c) Metallic new materials	48	(43)
	Total	90	(80)
3.	Measures for non-organic new materials industries (studies and research)	45	(43)
4.	Improvement of testing/evaluation systems: To facilitate the development of new materials, financial support is given to testing and evaluation centres engaged in standardizing testing methods and evaluation criteria promoting their use, and conducting tests and evaluations.		
	(Reference) Existing testing/evaluation centres for new materials: New Materials Centre (metals), established September 1986; Japan High Polymer Centre, established October 1985; Japan Fine Ceramics Centre, established May 1985.		

Table 14. *(continued)*

		FY 1990	FY 1989
5.	International activities: Japan participates in activities under the VAMAS (Versailles Advanced Materials and Standardization) Programme, launched as one of the Summit projects, along with the United States, United Kingdom, France, Germany, Italy and Canada.		
	* Budget to be allocated by the Science and Technology Agency	undetermined	(132)
6.	Diffusion of knowledge and products related to new materials		
	(a) Support for exhibitions of new materials		
	(b) Support for efforts to promote new materials by related organizations		
	D. SECURING STABLE SUPPLY OF RAW MATERIALS FOR NEW MATERIALS		
1.	Comprehensive development programme for rare metals (cooperative survey on natural resources development)	476	(462)
2.	Rare metals stockpiling	1 580	(1 542)
3.	Survey on availability and reserves and of mineral resources for rare metals	221	(330)
4.	Development of superconductive materials for power generators	147	(140)

Source: Basic New Materials Policy Office, Basic Industries Bureau, MITI.

Table 15. Republic of Korea, Highly Advanced National Project, 1992-2000
(Unit: thousand million won)

A. Advanced technology development	1992	By 2001
Highly integrated semiconductor	15	365
Integrated services and data network	20	250
High definition television (HDT)	26	113
Electric vehicle	3	72
Intelligent computer	3	115
Medicines and agricultural agents	8	136
Advanced production systems	83	1 308
Subtotal	158	2 359
B. Fundamental technology development		
Advanced materials	4	117
Next-generation transport systems	7	209
Biotechnology	5	241
Environmental technology	7	195
New energy resources	10	128
New atomic reactor	2	23
Human interface technology	2	40
Subtotal	37	953
Grand total	195	3 312

The "G7 Project", as the HAN Project is commonly known, allocates 121 trillion won (W) (approximately $160 billion) for 1992, the first year of the project. The technology-related ministries and agencies of the Republic of Korea will spend an estimated $3,000 million over the next ten years and this amount will be matched by an equal amount of investment in advanced technologies by private industry. The HAN Project is a first attempt to coordinate the research activities of various ministries and government agencies. This has been necessary due to the existence, hitherto, of an overlap of research programmes between departments, while budget allocation for each ministry has been too small to enable them to undertake large research projects. Most of the research will be undertaken by KIST and related institutes (affiliated to MOST). In addition KAITECH (under MTI) will coordinate and fund near market research by government laboratories, industry and universities.

Source: MOST and Nature, January 1992 and November 1991.

Table 16. Contents of three HAN projects
(Millions of won*)

	Government	Industry
New pharmaceuticals and agrochemicals	7 300	2 812
Antibiotics Herbicides/insecticides Hepatitis drugs/vaccine Anti-cancer drugs Anti-viral drugs Hypertension drugs Benzenoid germicide Other drugs and vaccines Screening of drugs and agrochemicals Common basic technology & international cooperation		
New advanced materials	2 959	1 544
High-strength aluminum Ceramics/ceramic engine Polymers Composite materials Heat- and wear-resistant materials High-density magnetic materials		
New functional biomaterials	132	132
Biodegradable polymer		
Total	10 392	4 489

Source: MOST, August 1992.

Note: Figures may not add up to totals because of rounding.

* $1.00 = 790 won.

Box 6. The Korean Institute of Science and Technology (KIST)

Objectives

(a) Developing creative and innovative original seed technologies;
(b) Performing large-scale national projects;
(c) Carrying out basic and applied research and development;
(d) Rendering R&D services to industry and other research organizations.

Brief History

February 1966	Korean Institute of Science and Technology (KIST) was founded.
February 1971	Korea Advanced Institute of Science (KAIS) was founded.
December 1980	Special KAIST law was promulgated. (KIST and KAIS merged into KAIST.)
January 1981	KAIST was registered and formally founded.
February 1985	Genetic Engineering Centre, an affiliated organization, was established.
September 1987	Research function was reorganized under the Central Research Laboratories.
June 1989	Korean Institute of Science and Technology was registered, separating from KAIST.
January 1992	KIST reorganized.

Background: The Advanced Materials R&D Group was formed as a special task force of KIST to promote advanced materials research, a strategic national project, after restructuring the original division-based research units.

Tasks: Effective implementation of advanced-materials related national projects.

Assessment of trends in advanced-materials technology and recommendation of development policy to the Government.

(a) Analysis of both domestic and international technologies and market trends;

(b) Forecast on future outlook of the advanced materials market.

Technical collaboration and joint R&D activities:

(a) Technical collaboration with other government-supported research institutes, universities, and research centres of private companies;

(b) Assessment of latest information through holding international symposiums;

(c) Joint R&D activities with overseas research institutes.

Planning, coordination, and selection of national research projects.

(Continued)

Evaluation of national project results and technology transfer to private companies.

Provision of manpower and facilities for national projects.

Major Advanced Materials R&D Projects

1. Development of advanced micro-electronic materials for the information-processing industry

In the 21st century, the localization of advanced micro-electronic materials for the information-processing industry will be required to meet the demands of a new market and to reinforce the international competitive power in this industry.

In order to advance in the information-oriented society, therefore, R&D has been carried out for the realization of high speed, great capacity, and multi-function in advanced micro-electronic materials.

Research Coordinator: Dr. Suk-Ki Min, Head, Semiconductor Materials Laboratory.

Major research achievements	Major research subjects
Crystal growth technology of Si and GaAs semiconductor materials Heteroepitaxial crystal growth of GaAs/AlGaAs Superlattice and HEMT structures by MOVD and VDE Device processing techniques of MESFET, HEMT, DH-LD and multiquantum well (MQW) Development of optical memory materials Development of magnetic recording materials	Research on low defect GaAs crystal growth Research on crystal growth and device Technologies of superlattice structure of ternary and quaternary compound semiconductors Fundamental study on 3D structure devices Research on high density recording media for hard disk Development of optical disk and code data optical memory system Research on preparation and synthesis technologies of high-performance polymer

2. Development of advanced base materials for industrial electronic devices

In view of the scarcity of natural resources and the abundant manpower, the development of production for industrial electronic devices is a promising strategic industry because it is intensively technology-oriented, highly value-additive, and very efficient in relation to investment.

(Continued)

Technological self-reliance must be ensured to establish a national predominance in international price competition by producing parts that are high function, multi-functionalized and miniaturized.

Research Coordinator: Dr. Hyung-Jin Jung, Director, Division of Ceramics

Major research achievements	Major research subjects
Surface active and electronic semiconducting ceramics/CO and fuel gas sensor Ceramic ionic conductor/oxygen sensor for steel mill and 0_2 trimmer Piezoelectric ceramics/FM filter, sonar (hydrophone) and gas igniter Shape memory alloy/actuator, temperature sensor and value Dielectric ceramics/MLCC, BL capacitor Amorphous metal alloy/magnetic tape and core Ferrite single crystal/magnetic head Thermo-electric alloy/thermo-cooling device Magnetic alloy/rare-earth metal magnet	Heat resistant structural ceramics (SiC, Si_3N_4) Development of IC packaging materials with low dielectricity Ultrasonic pulse generator and piezoelectric materials for sensors Materials for infrasensor Electrostrictive materials with high resolution to displacement/piezoelectric actuator devices mV-class ultrasonic motors Superconducting high materials with high Tc Electro-optical single crystal/polycrystalline materials and their applications High pressure synthesis and thin film technology of diamond Ceramic materials with high thermal conductivity (AIN) Ceramic processing by sol-gel method

3. Development of new aerospace materials

Development of the aerospace industry leads to high-added value and has a great influence on the development of other industries.

Moreover, transfer of essential and highly developed aerospace technology from the developed countries is under strict control for their own technology protection. Therefore, the development of domestic aerospace technology is a very urgent task for industry in the Republic of Korea.

For the establishment of aerospace technology and local production of new aerospace materials, research and development on new areospace engine and body materials, forming technology and material testing and evaluation technology are being performed.

Research Coordinator: Dr. Ju Choi, Director, Division of Metals

(Continued)

Major research achievements	Major research subjects
Nickel-base wrought super-alloy, Pat. No. 16420 (1984) Nickel-base cast super-alloy, Pat. No. 17099 (1984) Co-free nickel-base super-alloy, Pat. No. 17100 (1983) Heat resistance Ni-Cr-W-Al-Ti alloy, US Pat. No. 4,810,488 (1989)	Development of Ni-base super-alloys Oxide dispersion super-alloys Heat resistant Ti-Al, Ni-Al inter-metallic compounds Turbine part bounding technology Thermal barrier coating Ti alloys for high temperature High-melting point alloys High-strength, low-density Al-Li alloys

4. <u>Development of advanced materials for high-function automotives</u>

The automotive industry is strategically important to the Republic of Korea. R&D on high-function automotives will be essential in order to share the world market as well as to compete with important automotive developments in the 21st century.

Research Coordinator: Dr. Chung-Yup Kim, Director, Division of Polymer Science and Engineering

Major research achievements	Major research subjects
Electrically conductive polymers Transparent conductive polymer films Polymer sensors High-performance engineering plastics Polymer thin films Crystallization and interface of polymers	Lightweight and heat-resistant materials for engine peripherals Lightweight materials for automotive exterior Durable polymer coating materials turbo charger rotor (heat-resistant alloys, ceramics) Parts of ceramic turbine engine Lightweight structural materials (polymers, aluminium alloys, composites)

5. <u>Development of biomedical materials</u>

The demand for biomedical materials in the Republic of Korea is rapidly increasing with economic development and the extension of the medical insurance system. Therefore, there is a strong need to support the biomedical industry. Biomedical products are advanced technological items which are highly valuable and free from trading barriers.

At KIST, research is being carried out on artificial organs, therapeutic articles and biomedical membranes.

(Continued)

Research Coordinator: Dr. Young-Ha Kim, Head, Polymer Chemistry Laboratory

Major research achievements	Major research subjects
Hemodial-year Blood oxygenator Intraocular lens Transdermal therapeutic system Bone plate Artificial teeth roots Bio-absorbable suture	Blood oxygenator membranes Artificial kidney membranes Oxygen enrichment membranes Artificial blood vessels Materials for ophthalmiatrics Ceramica/polymers for artificial joint Artificial teeth and roots Artificial heart valves Dental materials Drug delivery system Biodegradable materials

(a) Advanced materials and components for high-technology strategic sectors in Taiwan Province of China[32]

Since 1982, the Materials Research Laboratories (MRL) have played a key role in Taiwan's Province of China upgrading of industry through materials developments and applications. MRL aims (a) to develop key material technologies which are essential to the development of domestic high-tech industries, (b) to promote industrial application of materials protection technology and (c) to assist local industries to upgrade their level of industrial developments. In order to achieve these objectives, several materials and associated technologies have been identified (summarized in table 17). Research and development priorities at MRL reflect national industrial development policies, which evolve according to the conditions facing local industry and the changes in the global economic environment. Currently, Taiwan Province of China is giving top priority to nine critical high-technology sectors for research and development. Consequently, several advanced materials, technologies and components deemed essential to the survival of these industries have been identified and will be given priority for advanced materials R&D in the 1990s at MRL. The nine industries and related materials technologies are given in table 18. Moreover, MRL has selected six areas to assist domestic industries in enhancing their competitiveness in the world market. These are: materials design, materials processing, materials treatment, characterization and evaluation, and materials reliability.

MRL was entrusted by the Ministry of Economic Affairs with the implementation of the "Industrial Materials Research and Development Programme" for FY 1985 to 1990. Concurrently, MRL also began development of new and key materials technologies in

[32] This information was kindly provided by Li-Chung Lee, Vice-President of ITRI and MRL General Director.

accordance with the developmental procedures—overall planning, new-technology development, technology transfer and industrial services.

In 1991, MRL entered phase II of development. The five projects from the Government are the following:[33]

(a) Key technologies of electronic materials programme, including two activities:
(i) Electronic-packaging technologies;
(ii) Material technologies of high-performance electronic devices;

(b) Key technologies of photo-electronic materials programme, including two activities:

(i) Photo-electronic semiconductors;
(ii) Organo-photo-electronic materials;

(c) Development of key technologies used in machinery industry, including three activities:

(i) Processing technologies for polymer-composite materials;
(ii) Fabrication and forming technologies for metal and ceramic materials;
(iii) Technology development for advanced materials;

(d) Materials selection and reliability improvement research projects, including three activities:

(i) Non-destructive testing techniques for the evaluation of structural components and advanced engineering products;

(ii) Life assessment programme for structural components;

(iii) Life extension programme of structural components;

(e) Application research on high T_c superconducting materials including two activities:

(i) High T_c superconducting materials development, forming and processing technologies;

(ii) Electronic device fabrication technology of high T_c superconducting materials.

MRL will participate in the ITRI integrated projects (an integration of manpower and facilities among different laboratories within ITRI to conduct research on specific topics). These include aerospace technology, HDTV, sensor, orthopaedic devices, industrial safety and

[33] Information courtesy of Materials Research Laboratories, Technical Activities, 1990.

health technology, industrial pollution control technology and industry and technology information services.

(b) National Science Council

In promoting science and technology development, the Government established the National Council on Science and Development on 1 February 1959. Over the years, this Council expanded, and the structure was changed to meet the current needs of the nation. In September 1969, the name was changed to the National Science Council (NSC).

The National Science Council falls under the auspices of the Executive Yuan (i.e. Branch) of the Government of the Republic of China. It (a) concerns itself with the purpose of science and technology; (b) sets policies governing science and technology development; (c) establishes long- and mid-term plans; and (d) evaluates the annual science and technology plans of each division of the Executive Yuan. The NSC, the Council of Economic Planning and Development, and the Research, Development, and Evaluation Commission make up the three agencies of the Executive Yuan dealing with policy evaluation. Together, they are responsible for following the planning of national science and technology development, evaluating actual progress. Additionally, the NSC effectively administers the National Science Development Fund (see figure 45) to promote national science and technology development, support academic research and develop the Hsin-Chu Science-based Industrial Park.

The major tasks of the National Science Council (see box 7 for detailed information) are the following:

(a) Promoting national science and technology development;
(b) Supporting academic research;
(c) Developing the Hsin-Chu Science-based Industrial Park.

(c) The materials research laboratories

(i) Establishment

Without materials there can be no industry. Material improvement therefore upgrades product quality, increases product value and even creates new industries. Recognizing its importance, Taiwan Province of China designated it as one of the key areas for research and development. In July 1982, the Materials Research Laboratories (MRL) was born. It is a non-profit, national laboratory operating as an arm of ITRI and is funded by both government and private sectors.

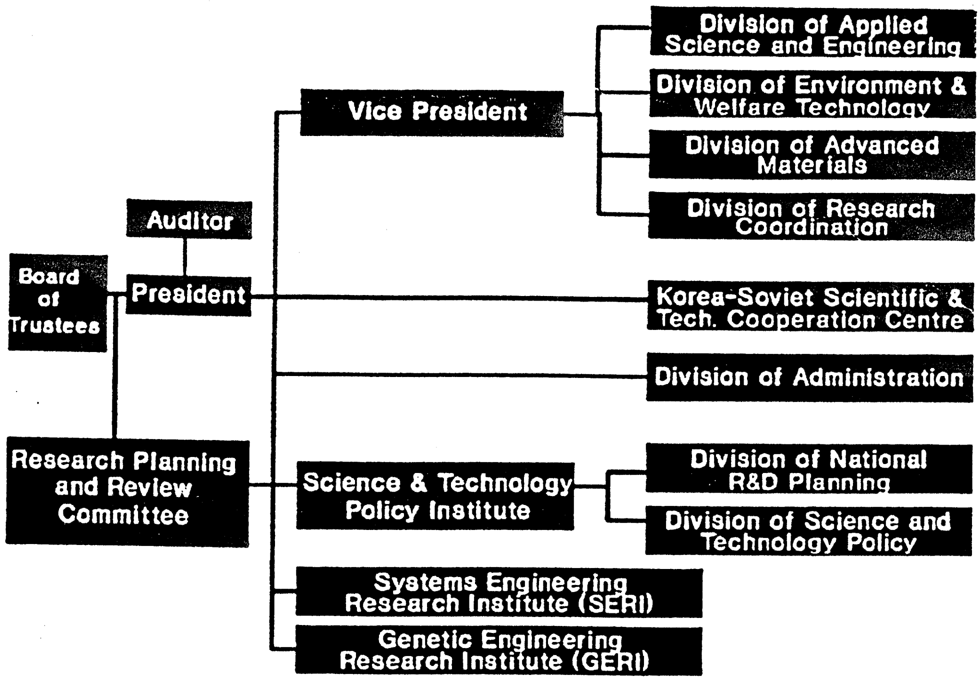
(ii) Main objectives

The goal of MRL is to maintain the competitiveness of industry in Taiwan Province of China. Therefore, most effort is centred around the following three areas of applied technology:

(a) Breaking up bottlenecks caused by inadequate or import-dependent materials;

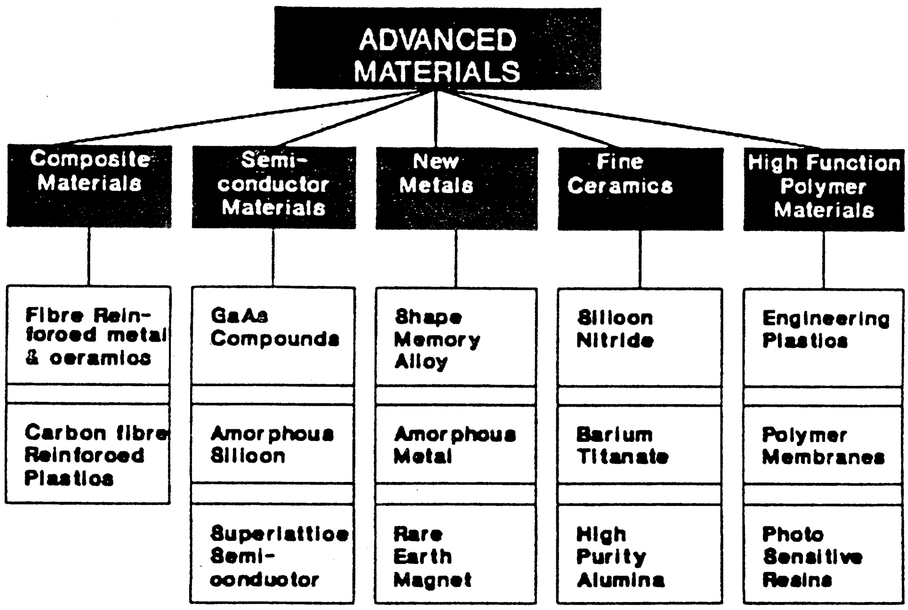
(b) Enhancing the added value of industrial products;

Figure 39. Organization of KIST



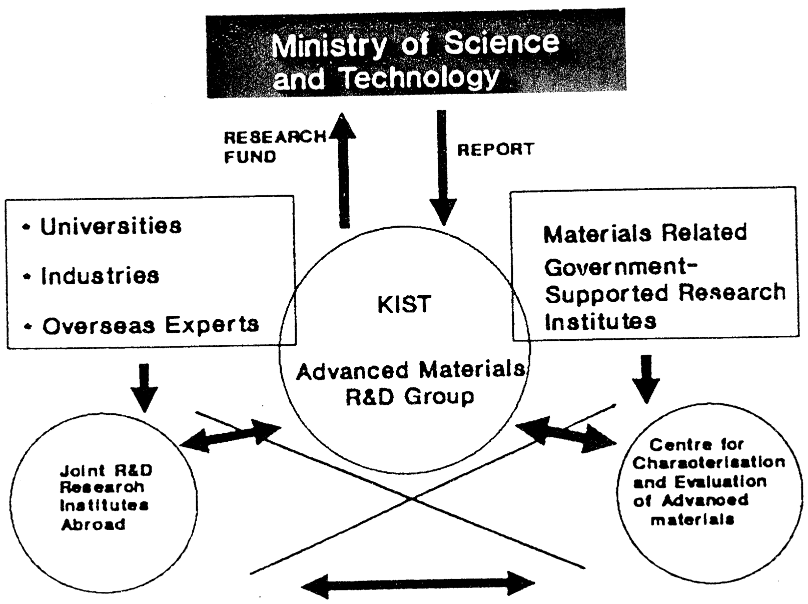
Source: KIST, August 1992

Figure 40. Classification of advanced materials for R&D activities



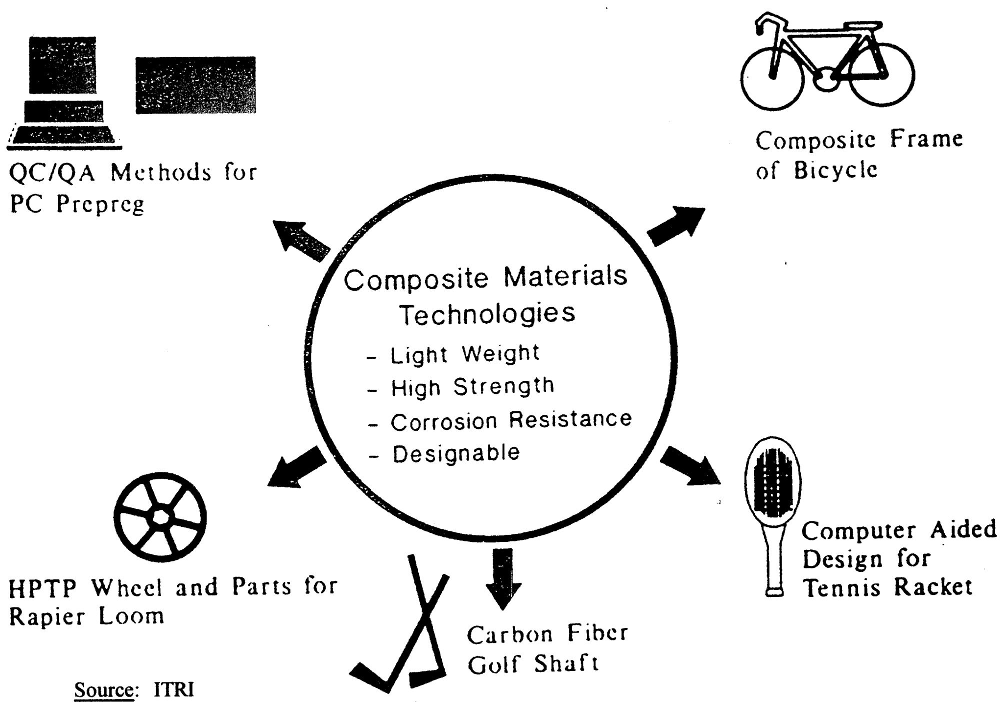
Source: KIST.

Figure 41. Operational procedure for advanced materials project



Source: KIST.

Figure 42. Industrial impact: improving conventional products and processes



Source: ITRI

Figure 43. Industrial impact: increasing product added-value/replacing imports

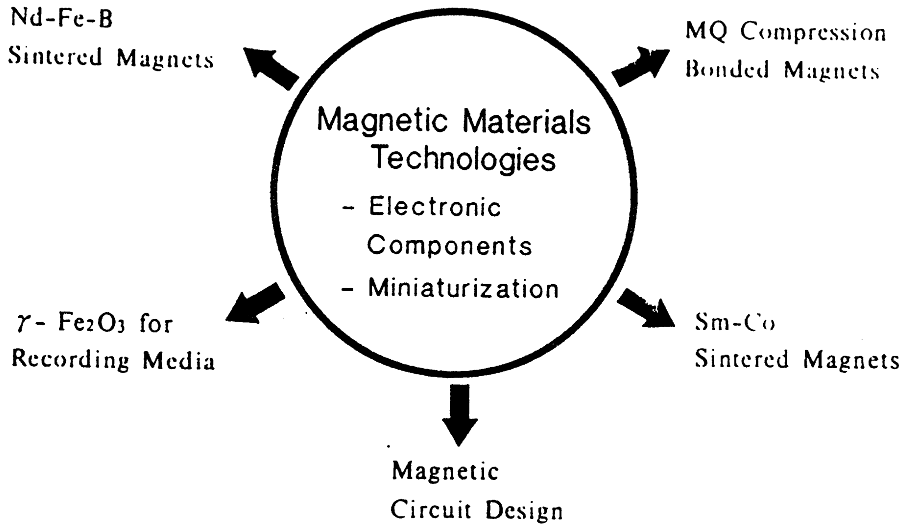
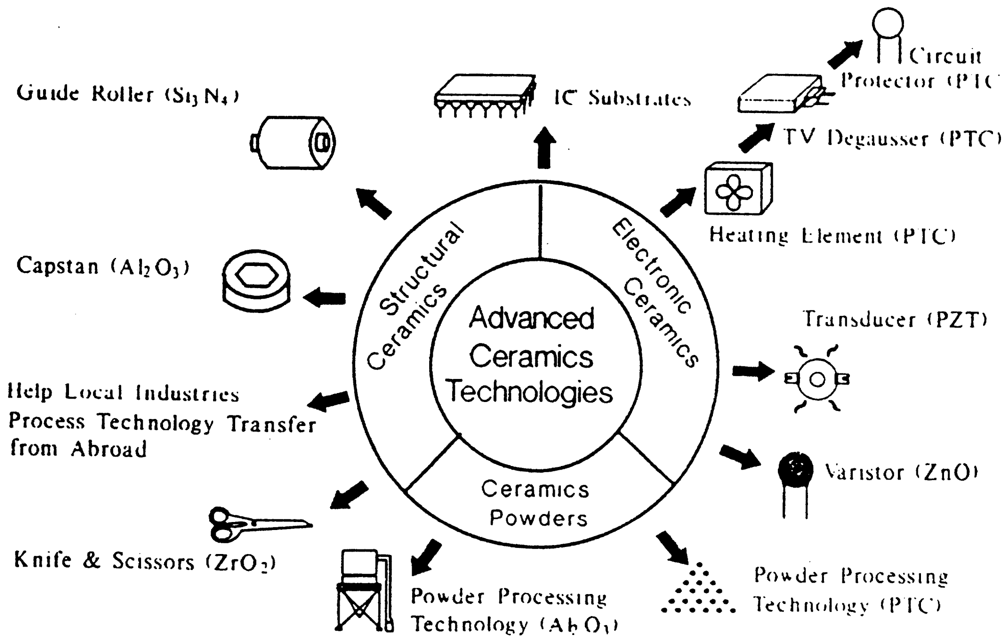


Figure 44. Industrial impact: promoting the establishment of high-tech industries



Source: ITRI - Materials Research Laboratories.

Table 17. Taiwan Province of China: development targets for materials science and technology in the 1990s

Materials	Development target	Items
Composite materials	1. Processing technologies for advanced composite materials 2. Structural design and application technologies	- Polymer-matrix composite materials (including high-performance thermoplastics), metal matrix composite materials, ceramic-matrix composite materials, hybrid composite materials
Ceramic and magnetic materials	1. Functional ceramics 2. Structural ceramics 3. Magnetic materials 4. High-temperature superconductors	- Piezoelectric ceramics, dieletric ceramics, ceramic packaging and substrate, solid electrolyte, phosphors - High-temperature ceramics (optical ceramics), bioceramics, synthetic diamonds - New-generation magnets, magnetic recording materials, high-performance soft magnet, specialty magnetic materials - High-temperature superconducting devices
Photo-electronic materials	1. Photo-electronic semiconductors 2. Organo-photo-electronic materials 3. Photo-electronic devices 4. Liquid crystal display material	- Single crystal and epitaxy of compound semiconductor, single crystal oxide, semiconductor optical fibre for communication, amorphous materials, high-performance Si - Photoresist, packaging technology for multichip module, colour printing material, colour display material, organo-optical material, conductive polymers

Table 17. (*continued*)

Materials	Development target	Items
Photo-electronic materials (*continued*)		- Optical information device, optical communication devices, non-linear optical device, integrated optics devices, optical sensor devices - TFT liquid crystal material, organic liquid crystal material
Metallic materials	1. Alloy design and process 2. Fabrication and forming technologies 3. Surface modification and interface treatment technologies	- High-strength aluminum alloys, super alloys, titanium alloys, copper-base alloys, ferro-nickel-base alloys, intermetallic alloys, amorphous metal - Precision casting, forging, powder metallurgy, near-net-shape forming process
Material technologies	1. Special fabrication technologies 2. Non-destructive evaluation 3. Life assessment technologies 4. Microstructural analysis	- Precision grinding, etching technologies - Ultrasonic testing, acoustic emission, and eddy-current testing - Degradation analysis, fracture mechanics, automated monitoring, tribology, life prediction - Surface and interface analysis, electron microscope analysis

Source: MRL, ITRI.

Table 18. Key materials technology for high-technology industries in Taiwan Province of China

Industry		Key materials technology and components			
1.	Communication	1. 2. 3. 4.	LD/LED Photo sensor Electronic packaging Optical fibre connector	5. 6. 7. 8.	Fabrication technology for micro-electronics Reliability engineering Microwave devices Modulators
2.	Information	1. 2. 3. 4.	OPC/toner Optical data-processing devices Electronic packaging Recording material	5. 6. 7. 8.	Display material Color printing material Magnetic head devices Thin film devices
3.	Consumer electronics	1. 2. 3. 4. 5.	Electronic packaging Magnetic recording material High soft magnets Battery material Electronic ceramic	6. 7. 8. 9.	Liquid crystal display material LED Magnetic head devices Powder metallurgy
4.	Precision machinery and automation	1. 2. 3. 4. 5.	Plastic forming Precision casting Sensing device/system Structural design/stress analysis Powder metallurgy	6. 7. 8. 9.	Composite material High-performance alloys Heat treatment Structural ceramic for mechanical parts
5.	Semiconductor	1. 2. 3. 4.	Semiconducting material Si.III-V Fabrication for Micro-electronics (photo-mask implantation) Electronic packaging PVD/CVD	5. 6. 7. 8.	Photoresistor Surface cleaning Characterization and quality control (non-destructive evaluation) Photo-electronic device
6.	Speciality chemical and pharmaceutical	1. 2. 3.	Organic chemical synthesis Chemical analysis Characterization and quality control	4. 5. 6.	Material formulation Material selection Scale-up research

Industry		Key materials technology and components			
7.	Aerospace	1. 2. 3. 4. 5.	Non-destructive evaluation Reliability engineering High-strength/weight ratio composites High-performance alloys Quality control	6. 7. 8. 9. 10.	Plastic forming Precision casting Fabrication technology for composite material Adhesive technology Structural analysis/stress analysis
8.	Health care	1. 2. 3. 4.	Biometal Biopolymer Bioceramics Thermal sprays	5. 6.	Characterization and quality control Close-die forging/precision casting
9.	Pollution control	1. 2. 3. 4.	Anti-corrosion engineering Material selection Reliability engineering Characterization and quality control		

Source: ITRI.

Table 19. World market in the year 2000
(Millions of US dollars)

Sector	Engineering thermoplastic resins		High-performance fibres		Advanced composites		Plastic	
	World	Taiwan P.O.C.	World	Taiwan P.O.C.	World	Taiwan P.O.C.	World	Taiwan P.O.C.
Aerospace	290	40	1 300	185	5 000	250	720	90
Automotive	3 000	360	70	10	2 000	200	5 400	650
Leisure	1 300	160	600	80	2 000	1 000	2 300	280
Industrial	760	90	160	20	<1 000	100	1 500	180
Electronic	4 700	560	100	15	<1 000	<100	9 000	1 190
Defense	440	50	170	20	1 000	100	1 100	130
Appliance/consumer	2 000	240	0	0	0	<100	3 200	380
Total	12 490	1 500	2 400	330	10-12 000	<1 700	24 120	2 900

Source: A.D. Little for CEPD.

Note: < = approximately.

(c) Developing and transferring new materials and technologies to the industry of Taiwan Province of China.

The major research areas in which MRL is engaged are indicated in table 22.

(iii) Status

MRL is staffed by over 600 people from a wide variety of disciplines, including material science, physics, chemistry, electrical engineering, mechanical engineering and chemical engineering. Using state-of-the-art facilities and equipment, this talented group has not only established MRL as a first-class research organization but has also helped industry in Taiwan Province of China to compete more effectively in the world market.

As of June 1989, MRL had obtained 16 patents (domestic and foreign), with 120 applications pending. Over 60 technology projects have been completed to the benefit of 80 companies.

(iv) Future

Since 1981 MRL has grown considerably, and this growth is expected to continue in the foreseeable future. MRL is poised to meet the ever-changing demands of the high-tech world in the near future and plans to strengthen its work in:

Key materials for electronic applications;
Key materials for opto-electronic devices;
Key materials for machinery;
Material evaluation and reliability;
High-tech superconductors applications;

(v) Technology diffusion

The material devices and technologies developed at MRL are transferred to industry under principles of fairness and openness. Follow-up assistance is given to manufacturers so that applications and production can be realized in the shortest time. The channels for technology diffusion are:

Information services;
Technology consultation;
Technology transfer;
Technology procurement;
Joint-venture projects;
Contract research;
Technology spin-off.

MRL also offers support services for testing and characterization; technical information and training; contract research; consultation services. Additional information is available from the Industrial Technology Research Institute, Building 77, 105 Chung Hsing Road, Section 4, Hsinchu, Taiwan Province of China 31015.

Table 20. World market sectors: opportunities for advanced polymeric materials manufactured in Taiwan Province of China

	New Products	Low entry barriers	Significant market opportunities	High value added	Feasible for Taiwan POC	Supports Taiwan end-use products
Automotive components			X	X	X	
Aerospace			X	X	X	
Industrial components		X		X	X	X
Leisure	X				X	X
Non-aerospace defense					X	
Electrical/ electronics	X		X	X	X	X
Appliances			X	X	X	X

Source: A.D. Little for CEPD.

VI. THE MATERIALS REVOLUTION AND DEVELOPING ECONOMIES

It is a sobering fact that the vast majority of developing countries remain heavily dependent on traditional primary-commodity production and trade as components of GDP and in terms of employment, government revenue and foreign-exchange generation.[34] The adverse world economic conditions of the 1980s and early 1990s have greatly exacerbated the well-known problems associated with the primary-commodity export sector, such as deteriorating terms of trade, instability of price and export volumes and revenues, slow or negative growth in real export earnings, and the rising spectre of protectionism in developed economies.

[34] See L. Kaounides, "The Materials Revolution and Economic Development", Institute of Development Studies, Bulletin, vol. 21, April 1990; L. Kaounides, "New Advanced and Improved Materials and Processes: The revolution in materials science and engineering and its strategic implications for developing economies in the 1990s", UNIDO, December 1990; and L. Kaounides "Advanced Materials and Primary Commodities", paper presented at Expert Group Meeting on Prospects for Industrialization Policies in Developing Countries, UNIDO, Vienna, Austria 4-7 April 1990. A condensed version of the latter appears in New Technologies and Global Industrialization, UNIDO, PPD 141, November 1989.

Table 21. Market niches for Taiwan Province of China in engineering thermoplastics

Material	Market sector	Specific examples
PA	Automotive	Nylon-PPO blends, TPE blends, plated mineral filled
PC	Automotive parts Tool housings	PC/ABS blends PC/polyester blends
POM	Electronics	Gears and bearings, switches
MPPO	Automotive	Nylon and polyester blends for body panels
	Electronics	Housings
PET/PBT	Automotive Electronics	Stampable mat for panels Interconnects, encapsulants, housing
PPS	Electronics Aircraft Automotive	Precision connectors, chip couriers Secondary structures Firewalls, floor plans, under-hood parts
PSO	Electronics Medical	Printed circuit boards, electrical connectors Instruments, packaging
PAR	Electronics Aircraft	Solid state ballasts, circuits boards Secondary structures (LCP alloys)
PES	Electronics	Printed wiring boards, 3D circuit boards, chip carriers, flexible circuits, wire coatings
	Aircraft Packaging	Secondary structural composites Microwave packaging
PEI	Electronics	Flexible circuit boards, molded circuit boards, chip carriers
	Aircraft Automotive	Interior liners, bonding layers Brake system and cooling system components
PEK's	Industrial Electronics	Motor parts, portable equipment parts Wire coatings, flexible circuits, connectors, burn-in sockets
	Aircraft	Graphite fibre components including primary structures

Table 21. (*continued*)

Material	Market sector	Specific examples
LCP	Automotive	Fuel systems, air inlet manifolds
	Electronics	3D circuit boards, vapour-phase soldered components
	Packaging	Barrier resin for flexible packaging
Engineering Thermoplastics Glossary		
PA	aliphatic polyamide	
PSO	polysulfone	
PC	polycarbonate	
PAR	polyarylate	
POM	polyoxymethylene (acetal)	
PES	polyether sulfone	
MPPO	modified polyphenylene oxide	
PEI	polyetherimide	
PET/PBT	polyethylene terephthalate, polybutylene terephthalate	
LCP	liquid crystal polymers	
PEKs	polyetherketones(various)	
PPS	polyphenylene sulfide	

Source: A.D. Little for CEPD.

Box 7. The National Science Council

PROMOTING NATIONAL SCIENCE AND TECHNOLOGY DEVELOPMENT

A. LONG- AND MID-TERM PLANS FOR THE PROMOTION OF SCIENCE AND TECHNOLOGY DEVELOPMENT

In order to effectively promote overall science and technology development, the NSC, along with other relevant departments, drew up the "Ten-Year National Science and Technology Development Plan" effective from 1986 through 1995. A mid-term plan specifying 12 strategic areas for science and technology development was also agreed upon.

(Continued)

TEN-YEAR NATIONAL SCIENCE AND TECHNOLOGY DEVELOPMENT PLAN

TARGET	STRATEGY
* Raising science and technology standards * Improving the quality of living * Accelerating economic development * Developing a self-sufficient national defense	* To improve public knowledge * To promote international cooperation * To expand research foundation * To raise the effectiveness of research and development * To encourage investment in R&D from the private sector * To develop high-tech industry

B. The establishment of science and technology statistical guideposts

	1985	1986	1987
National R&D funds (NT$b)	25.4	28.7	36.8
National R&D personnel	24 600	27 747	34 055
R&D funds as percentage of gross national product (GNP)	1.06	1.04	1.16
R&D personnel per 10,000	12.8	14.3	17.0

Preliminary evaluation: Covering all important national science and technology plans.

Ongoing control: Control and progress of all Executive Yuan-approved projects.

Final evaluation: Evaluation of project results.

Year-end evaluation: Evaluate and make improvements.

SUPPORT FOR ACADEMIC RESEARCH

A. Aid for research projects

To help promote national construction and to help best utilize personnel and financial resources, the NSC has developed a programme to aid short- and mid-term science and technology research projects. All public and private academic institutions and public research organizations are eligible for these funds. In 1989, the NSC supplied financial support to 3,157 projects.

(Continued)

Besides academic freedom in research, the NSC also encourages the cultivation of technical personnel at all levels. To this effect, the NSC is actively promoting 25 fields of mission-oriented study. These 25 fields are broken down into three more specific categories:

1. Interdisciplinary research programmes concerned with basic sciences	2. Interdisciplinary research programmes concerned with national economic development	3. Interdisciplinary research programmes concerned with improving the quality of life
* Surface physics * High-temperature superconductivity * Organic cyclo-addition reactions * Genontology * Large-scale oceanographic studies of the Kuroshio * Automation technology * Chinese herbal medicines and gandoderma * Mathematics education * Survey on mathematics and science literacy for daily life * Science education indicators * Cognition and learning	* Very large-scale integration (VLSI) * Materials science * Mandarin speech synthesis & image recognition * Artificial intelligence * Biotechnology * Aquaculture * Plant tissue culture * Environmental changes and the course of industrial development	* Hepatitis prevention * Genetic diseases * Disaster mitigation * Environmental * Genontology * The women's employment problem * Juvenile delinquency

B. Research grants

The NSC has established a system of research grants to help encourage research personnel to continue in their endeavours and to improve the research environment. Recipients of "outstanding" research grants received 0.3 million New Taiwan dollars (NT$) for two years in a row. Recipients of "excellent" grants received NT$ 0.18 million. "A" grant recipients received NT$ 0.12 million, and "B" grant recipients received NT$ 75,000.

C. The cultivation and recruitment of science and technology personnel (see figure 46)

The NSC uses three specific methods of funding to cultivate science and technology personnel:

(Continued)

(a) Cultivating research assistants through work on research projects;

(b) Establishing post-doctorate research positions;

(c) Choosing science and technology personnel to further their studies either domestically or abroad.

To strengthen domestic research, the NSC has allocated funds for the recruitment of overseas Chinese scholars. High-calibre research personnel are recruited to return to either short-term (less than three months) or long-term (three months to a year) positions in Taiwan Province of China.

D. Improvement in the research environment

1. Information services

The NSC has been actively setting up a national science and technology information network. The NSC has also been working to strengthen communication between domestic and overseas information offices, incorporating important foreign databases, establishing all types of domestic research reference materials and microfilm, and publishing academic periodicals in order to supply needed research information to domestic personnel.

2. Instruments and equipment

To help coordinate domestic science and economic development and to strengthen domestic capabilities and production of precision instruments, the NSC has set up the Precision Instrument Development Centre (PIDC). There are now eight Regional Instrument Centres throughout Taiwan Province of China. Valuable equipment and instruments are housed in these centres to facilitate administration and maintenance and to make the equipment available to as many researchers as possible. The NSC is now in the process of planning "National Research Laboratories" to improve the environment for research circles.

E. International cooperation

The NSC is actively promoting international science and technology cooperation and academic exchange to help raise the standard of domestic academic research. By taking advantage of personal interchanges between science and technology personnel, academic symposia, and international conferences, researchers from Taiwan Province of China can gain science and technology knowledge from more advanced nations and can better cooperate with foreign research bodies. Currently, the Taiwan Province of China maintains cooperative relationships with the United States, Germany, France, Austria, Japan, the Republic of Korea, South Africa and Saudi Arabia.

The Hsin-Chu Science-based Industrial Park (SIP): The Science-based Industrial Park was established to bring in high-tech industrial personnel, to lead the nation in industrial technology research and to accelerate national economic development.

Figure 45. Growth of the NSC Fund, FY 1981-1991

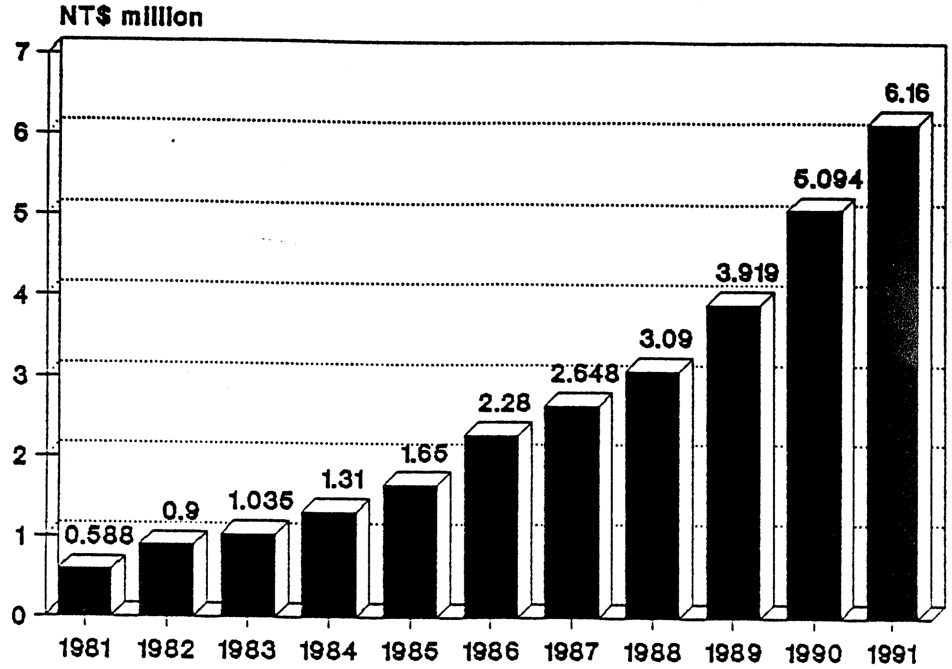
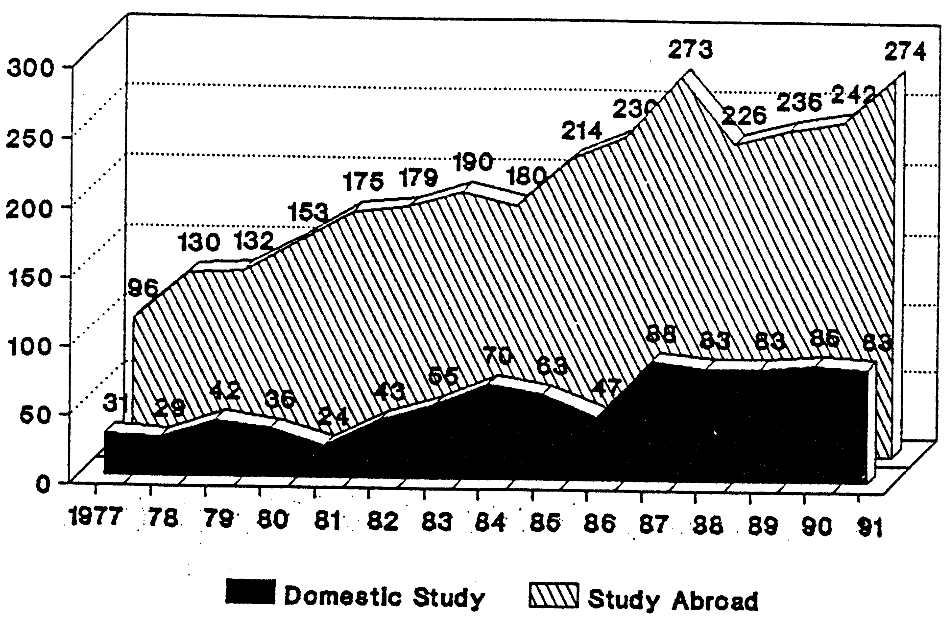


Figure 46. Employed science and technology personnel chosen for advanced study and research



Source: National Science Council, Taiwan Province of China.

Table 22. Materials Research Laboratories: major research areas

INORGANIC MATERIALS	
1. Fine ceramics:	Ferro-electric ceramics, semiconducting ceramics, multi-layer ceramic substrate, engineering structural ceramics.
2. Magnetic materials:	Permanent magnet, sintered soft magnet, magnetic recording media.
3. Superconducting materials:	New materials systems and processing, forming technology, applications.
METALLIC MATERIALS	
1. Powder metallurgy:	Atomization technology, powder injection moulding, amorphous brazing foils.
2. Metal melting & forming:	Co-Cr-Mo alloy, Ti alloy melting technology, Ti alloy remelting & forming, metal casting parts.
3. Solidification & alloy design:	Metal matrix composites, computer-aided alloy manufacturing, special solidification technology.
MATERIALS CHARACTERIZATION AND RELIABILITY	
1. Structural analysis:	Micro-structural analysis, chemical analysis, surface analysis.
2. Non-destructive evaluation:	Acoustic emission, ultra-sonic, eddy current testing, X-ray radiography.
3. Fracture & deformation analysis:	Applied mechanics, mechanical testing, failure analysis.
4. Corrosion protection technology:	Corrosion mechanisms at high temperatures, crack propagation detection and life assessment, corrosion protection services.

Table 22. (*continued*)

ORGANIC MATERIALS	
1. Organo-photo-electronic materials:	Circuit structural materials, circuit imaging materials, electrophotographic materials, optical recording materials.
2. Polymer composite materials:	Prepreg materials, structural design, material processing, material testing, product development.
3. Surface & coating technology:	Cer-Met composite electroplating, electro-etching of aluminium foil, surface treatment for multi-layered boards, surface treatment technical service.
SEMICONDUCTING MATERIALS	
1. Opto-electronic semiconducting:	Bulk crystal growth, epitaxial growth, device fabrication.
2. Thin-film technology:	Magnetoresistor, amorphous silicon semiconducting materials and devices.

Source: Industrial Technology Research Institute, Materials Research Laboratories.

It is clear that international commodity policy has made little or no headway since the optimism of the demands for a New International Economic Order in the early 1970s. Nevertheless, the problems remain and have, in certain respects, become more severe. Traditional modes of thinking in the areas of commodity policy, industrialization and economic development have been rendered inadequate, if not obsolete, by the advent of deep-rooted structural changes in world industry, many of which have been outlined in the present report. The commodity sector is permeated by the insights afforded by materials science and biotechnologies, while further downstream the manufacturing sector is being transformed by new methods of organizing production, flexible automation technologies and a host of other changes. Science, technology and industrialization strategies must therefore address these issues in the context of environmentally safe and sustainable paths of production and consumption. However, as the analysis of this paper indicates, many of these issues are materials-related. Strategies in the fields of environment, resource-based industrialization, the promotion of a viable manufacturing base, and science and technology must be closely integrated with the promotion and building-up of domestic materials-science and engineering capabilities. A critical minimum of domestic materials-synthesis and processing skills and infrastructure together with the formation of collaborative mechanisms for the conversion of new materials technologies to practical application in various industries will increasingly underpin successful export-oriented industrialization and sustainable development paths in the coming decades.

These considerations are now relevant to all economies but are likely to prove most critical in the case of lower income and least developed economies, whose commodity exports and trade performance in the 1980s combined with the recession of the early 1990s have led to unacceptable curtailments in domestic health and education expenditures and an inability to maintain a deteriorating infrastructure and productive capacity. Urgent measures are consequently required in the areas of debt relief, lower cost and enhanced flows of external finance, tariff reform and market liberalization, and measures to expand global economic activity and trade. These measures, together with other mechanisms designed to strengthen their position in commodity markets are necessary in order to ease the current difficulties, avoid further deterioration in living standards and meet the most pressing needs in the short to medium run. However, the onset of the new scientific and technological circumstances, which threaten existing patterns of specialization, comparative advantage and trade, necessitate a long-term strategic perspective. Each country needs to undertake a serious re-examination of its position *vis-à-vis* the international division of labour, the danger of erosion of existing sources of comparative advantage, and the financial, educational, scientific, engineering and institutional requirements for the selective acquisition of new sources of competitive advantage in regional and global markets. The danger of further marginalization of whole regions and countries within the world economy by the end of the decade is real and extremely serious. Urgent action is therefore imperative on the part of Governments, the private sector and the international community to avoid the impending disasters.

Certain countries and areas, such as India, Brazil, the Republic of Korea, Taiwan Province of China and Mexico, have displayed a remarkable degree of awareness of the emerging issues and are currently in the process of devising long-term industrial, scientific and technology strategies predicated upon the building-up of a domestic materials science and engineering infrastructure and expertise. At the same time, awareness of the issues involved and of the new sources of competitive advantage in world industry are relatively lacking in many developing and developed economies, at the level of the public and private sectors. Where awareness is high, the institutional and multidisciplinary intellectual resources required to devise appropriate responses and effectively implement policies may be lacking. This is why it is extremely important that international organizations act to promote awareness of trends and assist country efforts, where requested, to engage in techno-economic analysis, build up relevant institutions and channel resources to infrastructure development. In this realm, very little, if anything, is being done, apart from the pioneering and invaluable work undertaken internationally by UNIDO in the field of new technologies, including advanced materials. Hence, an important policy issue concerns the raising of awareness and mobilization of the considerable intellectual and financial resources of international organizations and donor agencies to assist developing economies to meet the challenges ahead. It is no exaggeration that for many regions and economies it may already be too late. There are cumulative gains of learning by doing in many MSE fields and late entry may be either very costly or impossible.

On the other hand, the materials revolution affords tremendous opportunities and potential gains of early entry in both traditional materials upgrading and new advanced materials for several developing economies. Materials science and engineering (MSE) integrates the structure-synthesis/ processing-properties continuum and thereby provides an interdisciplinary, unified approach in all classes of materials. This releases a vast potential for the improvement of traditional materials as well as for the design, fabrication and application of knowledge-intensive advanced materials tailored for specific end-use requirements. Thus, materials strategies have emerged as a critical issue in the international agenda, actively promoted by UNIDO for several years and now placed firmly on the policy agenda of Western Asian economies by ESCWA.

In recent years, a complex international and regional re-division of labour has emerged in which economies at different levels of industrial and economic development are shifting towards more sophisticated and higher-value-added products and processes. Advanced industrialized countries (IACs) in Europe, Japan and North America are shifting towards higher-value-added production employing advanced manufacturing technologies. They are closely followed by the newly industrialized economies, such as Brazil, Mexico, Taiwan Province of China, the Republic of Korea and Singapore. The latter three have announced plans to shift their economies to high technology and attain the status of fully industrialized economies by the year 2000 (2030 for Singapore).

These, in turn, are followed closely by second-tier NIEs and emerging economies such as India, Thailand and Malaysia, which is aiming to become fully industrialized by the year 2020, growing at an average of 7% per annum over the next 27 years. Several other economies are now moving into the positions vacated by the second-tier NIEs, and these include: Indonesia, the Philippines, China and Viet Nam. The evidence clearly indicates that as economies restructure and shift to higher levels of technological sophistication, they experience constraints from the side of domestic availability of advanced materials, parts, components and devices. In many cases, the requisite advanced components are unavailable from foreign sources, which often comprise competitors, or are prohibitively expensive or of inferior quality or not available on time. Hence, a certain degree of domestic autonomy, independence and competence in advanced materials technologies is essential in today's market-place. Moreover, domestic suppliers and supporting and maintenance firms are also important in sustaining competitive local manufacturing activities or attracting direct foreign investment in certain areas. Hence, the importance attached by Malaysia and Thailand to the promotion of domestic production of parts and components to deepen the industrial structure, support user industries and attract foreign investment of ever-increasing sophistication. The experience of the rapidly growing electronics industry in Malaysia clearly illustrates this tendency.

Improved materials and advanced materials tailored for specific applications are clearly beginning to play a critical role in the competitiveness of national branches of industry; in trade and investment flows; in technology transfer, licensing and joint R&D cross-border alliances; in the vocational decisions and global sourcing strategies of MNCs; and in the ability of traditional basic industries to defend themselves against the challenge posed by competing materials.

Hence, materials strategy for different countries has now emerged as a matter of urgent priority across the variegated regions of the developing world. Such strategies, formulated by specific countries and discussed at international meetings, are beginning to address a complex set of interrelated issues which relate to the building-up of a multidisciplinary MSE infrastructure and institutional skills in order to fully exploit and upgrade existing resources and/or enter into the development of new materials for production and use at different stages of the transformation of raw material into end-product. Several issues arise:

(a) The nature of the institutions involved and whether they should be reformed or replaced by new multidisciplinary ones;

(b) The mechanisms for implementing and managing the transition;

(c) The multidisciplinary nature of R&D in MSE and the expensive and advanced instrumentation, modelling, experimentation and characterization technologies involved;

(d) The role of standard testing and measurement procedures;

(e) Education programmes, curricula, and merging of university science departments;

(f) Training and retraining of human resources;

(g) Competition policy, mergers and acquisitions, joint R&D;

(h) Protection of intellectual property rights;

(i) Technology transfer and the role of MNCs;

(j) Links with the international scientific community;

(k) The role of Government versus the market and protection of "infant industries".

(l) R&D collaboration, precompetitive and near-market research among Governments, industries, and universities;

(m) Technology transfer from government R&D centres to private industry;

(n) The role of new materials in meeting basic needs;

(o) The role of new materials in meeting energy and environmental considerations and regulations.

Many of these issues and questions have been raised in a series of international meetings and were debated at an important expert group meeting in India.[35] The ongoing trends are not yet understood, and the generic issues that are relevant to all countries have not yet been identified. Each country must respond to these issues by devising a specific set of

[35] Final Report of the Expert Group Meeting on Materials Policy Issues, UNIDO National Materials Policy Project, TIFAC/Dept. of Science and Technology, Bangalore, India, 11-13 December 1991, UNIDO, July 1992.

measures appropriate to each domestic situation.[36] The ESCWA workshop must be seen as another step in the direction of elucidating materials-policy issues for the developing world in general and the ESCWA region in particular. Below is a very brief inventory of issues for discussion.

A. Building up MSE infrastructure and skills

The current revolution in MSE mandates a multidisciplinary approach to materials issues. Moreover, issues related to materials cut across several materials classes and industrial branches. This necessitates a transmaterial and transectoral approach in confronting materials policy issues, in contradistinction to the mono-material and specialized analyses employed hitherto. Boundaries between materials are eroding at both the science base and processing end and at the market end, where there is significant interpenetration of materials and several materials compete for the same application.

The multidisciplinary, transmaterial and transectoral approach must be reflected also at the level of institutions at the government level charged with the responsibility of collecting, analysing and interpreting materials developments and translating them into a set of coherent, long-term strategic objectives in the domestic economy. It is imperative that a multidisciplinary high-level unit of counsel be created, preferably under the direct supervision of the Prime Minister's Office, charged with the analysis, formulation, implementation and coordination of materials-policy issues in various ministries.

These multidisciplinary and transmaterial aspects are beginning to have an impact throughout the whole spectrum of organization of R&D laboratories, university departments, educational curricula, professional societies, and testing, measurement and evaluation institutes. At the level of university MSE departments, a central question for many developing countries is the choice between an MSE curriculum and degree course from existing departments in chemistry, physics and engineering or the costly creation of a new, multidisciplinary MSE department. In addition, a central question relates to the balance between basic sciences and engineering skills. In many developing countries, rather than devoting resources to frontier knowledge in basic sciences, it may be more feasible to focus upon the building up of a pool of engineering graduates who have studied at good MSE departments abroad and who can provide strong links between the basic sciences and practical engineering knowledge. A related issue is the need for developing economies to emphasize the development of engineering skills in both materials processing and the manufacturing base of the economy and the establishment of institutional mechanisms for the close integration of the two.

[36] See *Advanced Materials Technologies—Strategies for Growth*, L.C. Kaounides and R.S. Ganapathy (eds.), UNIDO/Institute of Materials, London, Spring 1993 (forthcoming) and *The Materials Revolution and Economic Development*, EADI/Frank Cass, L.C. Kaounides and M. Muchie (eds.), London, Spring 1993 (forthcoming).

B. ADVANCED AND IMPROVED TRADITIONAL MATERIALS TO MEET BASIC NEEDS[37]

The large and increasing basic needs of developing economies can be met[38] through more efficient utilization and upgrading of domestically or regionally available natural resources, and by using scientific insight and new and improved technologies. The materials revolution affords opportunities to developing economies to make fuller use of domestic materials, while minimizing energy requirements and environmental disruption. Included in this is the development of advanced materials designed to meet the needs of developing countries. That is, advanced materials must be tailored to meet the needs and specific requirements of industry and infrastructure in developing countries.

As Professor Pradeep Rohatgi has indicated,[39] the new-materials science and engineering base must be mobilized, internationally and within the developing world, to meet the needs of development in the coming decades. Although the science base of the new materials is common throughout the world, the direction of application and problem-oriented R&D cannot exclude the pressing needs and available resources of developing economies. Examples of new materials aimed at satisfying basic needs in developing economies are:[40]

(a) Genetic engineering for plants to get nitrogen directly from air;

(b) Genetic engineering for plants with stronger timber and fibres which can be pyrolysed to form high-performance fibres and carbon-carbon composites;

(c) Microbial processes to extract metals from ores and ocean nodules and to remove sulphur and silica from coal, bauxite and other minerals;

(d) Microbial processes to extract fibres and ultrafine ceramic particles from agricultural products and wastes;

(e) Solar photovoltaic materials with increasing efficiencies and decreasing costs; solar furnaces for processing materials;

(f) Materials for fusion energy;

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[37] "Current Revolution in New Materials: Opportunities for the Developing World", by Professor Pradeep Rohatgi and presented at the Regional Workshop on Advanced Materials Technology and Development in Asia and the Pacific, Minsk, USSR, 29 May - 2 June 1989.

[38] See "New Advanced and Improved Traditional Materials and Processes: The revolution in materials science and engineering and its strategic implications for developing economies in the 1990s" (UNIDO, 1990), upon which this section is based.

[39] See note 37.

[40] Ibid.

(g) Membranes made for polymers, ceramics and composites, with decreasing costs and improved performance for purification of water;

(h) Improved and inexpensive materials for housing from abundant and renewable resources such as sand, clay, rock, stones, laterites, and plant-based materials;

(i) Composites and ceramics with improved performances based on abundant elements like Al, Si, C, N and plant materials;

(j) Direct reduction of iron and aluminum, employing low-energy processes that use solar and biomass energy;

(k) Recyclable materials with cascading downgraded application with longer life and resistance to corrosion, oxidation, wear and fatigue;

(l) Rapidly solidified materials to reduce energy losses;

(m) Surface and interface processed materials with tailored structures and properties to meet specific needs;

(n) High-performance nano-structured materials, nonequilibrium and metastable structures;

(o) Room-temperature superconductors;

(p) *In situ* polymer composites;

(q) Tough ceramics;

(r) Net shaped materials fabrication;

(s) Parts consolidation through single-step moulding of complex shapes.

To the extent possible, such materials should be "...small, lighter, longer lasting, low cost, low energy and recyclable based on abundant and renewable resources and can be locally processed using simple and employment generating non-polluting technologies".[41]

In housing, MSE can examine alumina silicates, earth, stone laterite and clay-based products, which are readily available, and improve brick performance. In addition, modern materials science can also focus attention on renewable resources such as plant-based construction materials (e.g., bamboo, sisal, grasses, and wheat straw) and improve their performance for housing.

In the area of bio-processing of materials, advanced genetic engineering may lead to a strengthening of wood and fibres. Microbiological processes can also be used to extract

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[41] Ibid.

metals, and yet, other microbiological technologies can be used to extract fibres and ultrafine powders of silica from plant-based materials to make advanced ceramics and composites.

Moreover, new advanced materials and inexpensive membranes and filters can be developed to purify and desalinate water as well as meet the needs of production, transportation and storage of food. The United States-based aluminium producer, Alcoa Corporation, is currently researching into new advanced packaging materials for food and post-harvest products, of great relevance to developing economies.

C. Raw materials for advanced materials

Many developing economies possess materials and/or technological and human-resource skills that are directly relevant to the production and use of new advanced materials. Hence, the evolving materials era also offers opportunities to developing countries, where appropriate, to gradually enter new-materials production, quality control and trade at several stages of the transformation of the raw material into final products.

1. *Neodymium supermagnets*

Consider, as an example, the rare-earth element, neodymium[42] and its place in the new generation of permanent magnets. Neodymium belongs to the rare-earth "lanthanide" group of elements. Over 95% of existing permanent magnets are alnico or hard-ferrite-type magnets. Currently, the highest energy product of all practical permanent magnets is provided by the rare-earth cobalt magnets. Nevertheless, there are indications that the new generation of supermagnetic materials, as the new, rare-earth magnets neodymium-iron-boron are known, could replace the ferrite, alnico and rare-earth samarium-cobalt magnets. Neodymium is derived from three main minerals: bastnasite, monazite and zenotime and constitutes about 17%, by weight, of all rare earths mined. The main producers of rare-earth minerals are to be found (in order of importance) in the United States, Australia, China, India, Malaysia, the former USSR, Brazil, Canada, Sri Lanka, Thailand, Zaire and Madagascar. Neodymium constitutes about 13% of rare-earth content, and the distribution of its reserves is shown in table 23, indicating a 100-year life.

Taking advantage of the opportunities offered by neodymium and of other rare earth elements in magnetic-property applications and in advanced ceramic and glass technologies will doubtlessly involve familiarization with a variety of complex extractive and processing methods for rare earths, including lengthy processing routes such as metallothermic reduction, electromining and the new molten salt extraction process "neochem" for neodymium. In addition, developing economies will need to employ RSP-PM (rapid-solidification processing and powder metallurgy) technologies, as well as other, more recent techniques, to produce the new range of permanent magnets based on neodymium.

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[42] "Neodymium Supermagnet—Key Material for Tomorrow's Electrical and Electronic Industry", by N.C. Kothari and presented at the Regional Workshop on Advanced Materials Technology and Development in Asia and the Pacific, Minsk, USSR, 29 May - 2 June 1989.

2. *From metallurgy to ceramics*[43]

Many developing economies possess considerable practical experience, skills and in-place technologies in metallurgy and engineering. These can be judiciously directed towards forward integration into higher-value-added fabricating activities. However, they can also be tapped and transformed, in the context of a strategic reorientation and transition, towards ceramics production and use. Utilizing and building upon existing strengths, economies such as that of Zambia, for example, can transfer metallurgical skills and technologies relatively easily into ceramics, such as dielectrics and ferrites, the production of which has gradually been relinquished in Western Europe and the United States, while Japan remains a major producer.

The following is a brief outline of the transition requirements:

(a) Existing mining engineers and metallurgists would become ceramists. Qualified chemical engineers, materials scientists or chemists/physicists could also apply themselves to ceramics;

(b) Availability and training of local technologists and technicians/operators;

(c) Joint ventures, technology transfer and local training programmes with foreign firms, which could include firms in other developing countries such as, for example, Brazil or the Republic of Korea;

(d) Metallurgical furnaces and kilns would be converted to oxide/nitride ceramics.

This transition is not difficult; metallurgy is easily transferred to ceramics. The process involved is:

Production BaTiO
Blend BaCO + TiO + additives
Calcine at 1,000-1,100 degrees C - BaTiO powder
Add organic binders (cellulose, etc.)
Mill - fine powder
Press ceramic shape - green body
Stack in cheap oxide utensils (batts, trays, etc.)
Sinter at 1,300-1,400 degrees C - dense ceramic body, of final shape
Apply electrodes - silver-based alloys and paints
Brush and spray - fire at 500 degrees C - capacitor

Similarly, for ferrites use ZnFe O, for substrates use Al O, and for piezoelectrics use BaTiO or PbZr Ti O. Markets for such materials and components are to be found in consumer electronics, radios, and television sets. They can be used as starting capacitors for fluorescent lights, etc. Quality control involves chemical and X-ray analysis.

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[43] The detailed discussions and suggestions in this section appear, courtesy of Professor F. Ainger of Plessey Research (United Kingdom).

Table 23. World neodymium reserves

Country	Estimated reserves (kg x 10^3)
United States	650 000
India	400 000
South Africa	15 000
Central Africa	6 000
Malaysia	5 000
Brazil	5 000
China	4 600 000
USSR (former)	70 000
Australia	8 000
Others	50 000

Source: N.C. Kothari, 1989.

Clearly, it makes sense for a number of developing countries in Africa, Asia and Latin America to seriously consider entering this field in order to supply domestic and regional needs for such materials in consumer electronics industries. The technologies involved are old and not hindered by patents, and the raw materials (e.g., technical barium) are cheap and accessible. Once entry has been achieved at this end of the market and these technologies are mastered, firms can then move on to more sophisticated products and technologies, since the technologies involved are similar.

D. ADVANCED MATERIALS FOR THE ENVIRONMENT

Finally, it is important that the extraction, processing, application and recovery of advanced materials address the issues of environmental degradation and health hazards. These issues are no less significant or relevant in developing countries than they are in IACs, and they will exercise increasing influence over industrial strategy in NIEs in South-East Asia and Latin America in the 1990s. Research on environmental technologies in chemical production and use is of utmost importance for ESCWA member countries.

While materials production and use are inextricably being linked to environmental concerns and, hence, increasingly to environmental and safety regulations, the materials revolution offers scope for developing materials and technologies that can reduce or eliminate pressure on the environment.

In the production of materials, pollution can be generated by solvents during a curing cycle;[44] health risks may be present due to particle dispersion of ultra-short fibres in ceramics or composite fabrication; the danger of inhalation of fumes may be present in the production of reinforced plastics. In the use of materials, environment and health may again suffer and must therefore be protected. A neglected but very important area concerns pollution generation by tarred surfaces (e.g., roads, car parks, airports, roofs, etc.). Tar is essentially the rubbish of the petrochemicals industry. It contains asphaltenes, heavy metals, etc., and can cause massive air and rainwater pollution, evaporation, water pollution, etc. It is beginning to have deleterious effects also on pollution-free soils in developing countries. Advanced-materials solutions here could include the enclosure of tar and gravel in high-strength polymer pouches with controlled surface properties. This would give a large impetus to polymer producers, public-works companies and oil companies, enabling them to eliminate residual tar and use the solid residues from the chemical industry's incinerator plants.

A major concern affecting all industries is the problem of recovery and recycling. New advanced materials pose greater threats and face even bigger difficulties in this area. New materials are increasingly complex (e.g., composites or laminates) and more difficult to recover without being destroyed. They are non-neutral to the environment in the sense that they do not decompose and may ultimately be harmful. Fibre-composites cannot be discarded after use, and the technology does not exist to reuse the matrix fibre. Scrapped cars, washing-machines, etc., are increasingly less attractive for recovery and more difficult to separate.

The major areas of concern in the 1990s include the development of high-technology recycling industries, without which new materials will find it increasingly difficult to diffuse. International cooperation would be needed to develop technologies and industries to deal with recovery processes for household and industrial wastes, with MSE in research labs and universities being directed to meet these needs.

Environmental concerns will be crucial to product development and materials selection in manufacturing industry and in public utilities in the 1990s. New-materials capabilities can assist in providing solutions to environmental concerns and regulations and in the development of continuous, non-destructive testing and sensor technologies that can enhance the reliability and safety of components and final products.

Developing economies need to participate in the efforts to harmonize regulatory policy on environment, materials and health in IACs, as well as the efforts to regulate production of hazardous materials. In addition, collective efforts must be made to direct MSE towards resolving environmental problems and energy generation and distribution in developing regions through the production and use of new materials.

E. MSE AND IMPROVED TRADITIONAL MATERIALS

The first important point to note is that the insights of materials science and engineering can and must be used to improve the properties and processing technologies of traditional materials.

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[44] P. Cohendet *et al.*, *New Advanced Materials* (Springer-Verlag, 1988).

Tremendous scope exists for improvement in the processing technologies of traditional materials, and this is a point of obvious significance to developing economies, whether the aim is to produce for the world or the domestic/regional markets. Even if economic and political forces are inexorably leading towards the redeployment of major portions of basic-materials processing branches to developing regions, this will necessarily be accompanied by the employment of best-practice advanced-processing and fabricating technologies. Sourcing of commodity exports from developing countries will be on the basis of cost and quality.

Furthermore, given the pressures of the world market and user industries for higher quality, durability, and reliability no industry or economy can afford to ignore the improvement of traditional materials at any stage of the materials cycle. This applies to materials selection in a range of manufacturing activities, from designer dominated, small-scale, flexibly specialized industries, such as clothing, furniture and footwear, to the provision of materials, components and sub-assemblies for the emerging high-tech and flexible mass-production industries such as automobiles. The decision to locate in or source from developing economies in the 1990s will be greatly affected by the quality and reliability of the materials offered. The availability of a network of supplier and maintenance industries is also becoming a critical element in the locational decisions of MNCs.

Successful efforts have been made to improve the properties of commodities such as natural rubber, wool and cotton as compared to synthetics, and this may point to future collaborative efforts among developing countries on a cross-commodity or regional basis. Of course, this may lead to a situation in which one group of countries utilizes advanced scientific research to improve natural rubber (as Malaysia has successfully done, while also moving to higher-value-added rubber products) while another group promotes synthetic rubber. A similar situation could occur with natural fibres versus man-made fibres (e.g., in the Middle East).

Finally, it must be noted that many metals industries have been fighting back by utilizing MSE insights to improve properties and processing techniques and forging close links with customers in user industries (e.g., steel-auto or aluminium-auto partnerships). These developments are of vital importance to metal producers in the developing world.

VII. CONCLUSIONS

The countries of the ESCWA region are being presented with an historic opportunity. They can mobilize the region's considerable intellectual, scientific, financial and natural resources in a systematic and strategic effort to satisfy basic needs domestically and shift towards high-value-added, knowledge-intensive industrial production and high technology by the early part of the 21st century. Or they can wait for the scientific, technological and manufacturing developments identified in this study to overtake them, rendering many commodity and manufacturing activities uncompetitive, with devastating consequences for output, employment, exports, growth and living standards in the coming decades.

The challenge posed by the materials advances and by the new manufacturing, requires responses at the level of government institutions, academia, research centres and, importantly, private industry, both at the level of individual countries and collectively in the framework of regional cooperation. It is likely that at the level of both the Government and the private sector, the small share of manufacturing exports to the world market, for example, would appear to obviate any need for concern, and domestic industry could thus safely carry on as before. Nothing could be further from the truth. Industry has now become globalized in terms of production, marketing, R&D activities and sourcing and procurement of materials, parts and components. There is, in fact, no long-term hiding place behind national barriers.

The changes under way will have a dramatic impact on export markets, the survival of domestic industry in the face of import competition, the locational strategies of foreign firms, the local content of domestic manufacturing activities by foreign firms and the sourcing of high-quality, low-cost materials and components from the region.

Upgrading the quality of traditional materials and the availability of metal and chemical specialties will be crucial to the competitive advantages of domestic industries at home and abroad. Moreover, domestic and in-house technological, engineering, R&D and design skills will be critical in attracting and forming cross-border collaborative R&D alliances or, indeed, fully utilizing licensed technologies.

Materials strategies today are inseparable from the overall thrust and direction of science, technology and industrialization strategies. Domestic materials development is governed by the stage of development of user industries and their potential for growth and for increasing sophistication of production operations and products. Thus, the opportunities for upgrading of traditional materials and entry into specialties and new materials (e.g. high-performance polymers or polymer matrix composites) is determined to a large extent by the size and requirements of user industries in the region.

Once a foothold has been gained in the selected points of entry of specific stages of the materials production cycle, the cumulative gains learning by producing and using such materials would enable early entrants to climb higher onto a steep learning curve and expand new materials design, processing and application activities for domestic industry and the world market.

The domestic availability of a critical minimum mass of materials-synthesis and processing-engineering skills would facilitate the removal of obstacles to manufacturing competitiveness and act as a critical enabling technology for the shift by industry to higher-value-added production and high-tech activities in the region.

Industrial and sustainable-development strategies must be formulated in close association with materials-science and technology strategies. This is a central conclusion of the present study.

Given the critical importance of materials for socio-economics and industrial development, it is incumbent upon all countries of the region to urgently address the need to build the institutions, infrastructure and collaborative alliances university-government-industry research and its effective transmission into the productive sphere. A number of issues then arise:

(a) Firstly, building up centres of excellence in pure science is virtually useless unless basic research is directed towards application and resolution of practical industrial and social problems;

(b) Secondly, it must become remunerative for material scientists to direct their resources towards the resolution of pressing problems in terms of water purification and filtration, housing materials, environmental sustainability and clean technologies, food preservation and packaging, transportation, energy generation, and upgrading traditional mineral and agricultural commodities and fibres;

(c) Thirdly, the emphasis in the region must be on materials synthesis and processing capabilities in both traditional and new materials. The emphasis on engineering and processing skills must be closely connected to a strong emphasis on strengthening engineering skills throughout the manufacturing base. This much has been learned from the Japanese example, which is now being emulated by the Republic of Korea and Taiwan Province of China, and, importantly, by the United States;

(d) Fourthly, building the MSE infrastructure must, therefore, pay serious attention to the acquisition of processing engineering skills at universities and government and industrial laboratories and research centres. This is not enough, however;

(e) Fifthly, materials design, synthesis and processing must be application- and user-oriented. At one level this implies that a close institutional framework exists which transmits fast and efficiently new-materials development into commercial applications. Thus, industry's needs must figure prominently into the materials R&D programmes at government and university research institutes. (Here, the ESCWA member countries could profit enormously by studying the role and collaborative mechanisms that exist between government research centres in the Republic of Korea, Taiwan Province of China and Singapore, and industrial users in chemicals, metals, electronics, cars, machinery, leisure goods and aerospace);

(f) Finally, it is imperative that close collaborative mechanisms be formed between those firms that produce materials and those that use them. As previously stated, materials, product and manufacturing engineering must be conducted simultaneously for technical, organizational and competitive reasons (e.g. fast product renewal, tailoring material to user specifications, near net shape processing, etc.).

An additional, and critical requirement is the promotion of R&D and design skills in industry, an area badly neglected in many NIE's and which is proving disastrous in their attempt to capture or maintain a competitive advantage in the world market. The ESCWA region must address this issue now, especially in the area of design and R&D skills and incentives for small firms in manufacturing.

Close linkages should be created between materials design and synthesis and product design through collaboration of research institutes and private firms. For example, ITRI in Taiwan Province of China entered advanced- composites research in 1982. It subsequently began to orient its knowledge base towards application. A private firm approached it for the use of polymer composites in bicycles. Here, ITRI was obliged to learn the concept of "bicycyle" as a product; then, through close collaboration with the firm, it designed both composite material and bicycle frame simultaneously, leading to a commercially successful, high-volume, low-cost bicycle employing advanced-composite technologies.

The countries of the ESCWA region should begin to build up and strengthen MSE capabilities. Urgent consideration must be given to the establishment of multidisciplinary, multi-material, research, processing and applications centres, which will form an indispensable tool in the effort to address domestic socio-economic needs and the enhancement of the scientific and technological competencies of local industry. The region possesses a strong comparative advantage in oil-refining, petrochemicals and commodity chemicals as well as energy-intensive industries such as aluminium-smelting and steel, which comprise the major component of industrial production. Thus, long-term survival depends on acquired comparative advantage through the building-up of regional, domestic and in-house multidisciplinary R&D and engineering competencies. In order to upgrade both materials and processing or fabrication technologies, access to foreign technology and tapping into the global science and technology base are crucial. At the same time, creating a high-level scientific and engineering research centre could substantially assist local industry to shift output towards chemical specialties, engineering polymers, pharmaceuticals, specialty steel, aluminium alloys, etc. in accordance with the current stage of development of user industries and future objectives for a strategic reorientation of materials-producing and -using sectors in the region.

While such centres would be relevant at the level of individual countries, it may, in fact, be more prudent to pool intellectual, scientific, technological and financial resources into the establishment of a single regional materials research and processing centre serving the region's needs in terms of the environment, basic needs and the upgrading and strategic reorientation of industries. This centre could collaborate with research centres, both private and public, in the individual countries. The establishment of a new materials research centre to serve the interests of Arab countries in the framework of regional cooperation must be given urgent priority by the countries of the region as time is running out and in many areas it is already very late.

Many countries have already devoted considerable resources in building up their MSE infrastructure and in establishing or strengthening materials research centres with a strong orientation toward applications to address the emerging needs of industry. The ESCWA member countries must immediately start drawing plans for the establishment of such a centre within the next two years. Such a centre could also act as a means to reverse the very serious brain drain away from Arab research. The Governments and policy makers of the region should reflect on the likely disastrous consequences of inaction on this issue.

Annex I

THE CHEMICALS INDUSTRY IN JAPAN[1]

According to the latest data available,[2] the Japanese chemicals industry, providing a diverse range of products from petrochemicals to fine chemicals, accounted for 7.4% of total shipments in the manufacturing industry, making it the fourth largest industry (see table A.1). For the last four years, the industry has grown rapidly on the basis of strong domestic demand, although there were signs of deceleration in 1990 as compared to the previous three years (see figure). In 1990, chemicals exports from Japan were valued at less than $15.9 billion (6.5% of total exports from Japan) and imports at just over $16.0 billion, making for a deficit of more than $170 million. The industry has been in trade deficit since 1982. In terms of a regional breakdown, trade in chemicals products with advanced economies such as those of the United States and the EEC continue to be in deficit, whereas trade with South-East Asian economies such as Taiwan Province of China and the Republic of Korea are in surplus (tables A.2 and A.3).

Investment in plant and equipment in the chemicals industry has been growing at an average of 10% per annum in recent years, given strong domestic demand for chemical products. An important component of investment expenditure is accounted for by the aggressive pursuit of R&D by chemical corporations in an attempt to improve competitiveness, innovation capacity and technological capabilities (tables A.4 and A.5). Together with deteriorating corporate performance, slower growth in demand and adverse financial conditions, investment is forecast to decline in 1991. While wholesale prices declined during 1981-1988, there was a slight rise in 1990. Costs rose by 4.9% in 1990, but this was not reflected in the price rise, leading to a deterioration in business performance during the year (tables A.6, A.7 and A.8).

A. STRUCTURAL ADJUSTMENT

Following the two oil shocks of the 1970s, the Japanese petrochemicals and related industries faced a period of sharply increased raw-material and feedstock prices together with overcapacity as a result of lost competitiveness and contracting markets domestically and abroad. The Temporary Measures Law for the Stabilization of Specific Depressed Industries came into effect to deal with such problems and expired in June 1983. This was followed by the Temporary Measures Law of the Structural Adjustment of Specific Industries (Industrial Structure Adjustment Law), enacted in May 1983. Eleven sectors of the chemicals industry were covered: ammonia, urea, phosphoric acid by wet process, fused phosphate, ethylene oxide, rigid PVC pipe and styrene. Such sectors were required to prepare plans for shutting down and scrapping excess capacity and measures involving forms of business collaboration and so on. In ethylene, for example, nearly a third of the total production capacity of 6,350,000 tonnes prior to disposal were either scrapped or shut down as a result.

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[1] This annex, together with annexes II and III, is attributed to L. Kaounides, UNIDO Technology Trends series, Autumn, 1992 and may not be quoted without permission.

[2] This section is based on data and information kindly provided by the Japan Chemical Industry Association.

Following a successful implementation of rationalization and collaborative measures by the designated industries (except for fertilizers) and more favourable economic conditions, the Industrial Structure Adjustment Law was abolished in June 1988. Subsequently, the establishment of new production facilities or the expansion of existing facilities was deemed to be the responsibility of each of the chemical companies. Nevertheless, companies intending to invest in new replacement or expansion capacity are required to make such information public and submit prior notice to MITI. By April 1989, the capacity originally shut down which was to be restarted amounted to 690,000 tonnes per annum, and new capacity expansion amounted to 530,000 tonnes per annum as of May 1989. On the other hand, the industrial structure adjustment is to continue in three groups of fertilizers and liquid oxygen.

The Industrial Structure Council, which acts as an advisory body to MITI, produced a report in June 1989 on "The Petrochemical Industry in the 1990s and Desirable Policy Measures" in which it made recommendations on the future course of the petrochemicals industry following the abolition of the Structural Adjustment Law. Policy recommendations for the 1990s revolved around three themes, namely "internationalization", "joint collaboration", and "individual characterization". With regard to plans for the introduction of new ethylene plants, the report warned that, were all plans to be implemented, a situation of substantial overcapacity would arise. It suggested that expansion by the companies concerned should correspond to demand, utilizing cooperative arrangements such as joint undertakings.

B. New ethylene capacity on stream in East Asia (1990-1991)

In Japan, several new small facilities have been in the planning stages, engendering a steady expansion of capacity for ethylene and its derivatives in 1991. On the other hand, derived demand for petrochemical products (e.g., industrial components for automobiles and machinery, and household goods) is likely to slow down following the expected deceleration in economic activity. Consequently, there will be a relaxation of the tight supply-demand balance which provided the foundation for the favourable performance of the petrochemical industry, leading to a deterioration in profitability in fiscal year 1991.

Table A.1. Position of Japanese chemicals industry (1989)

	Value of shipment (billions of yen)	Number of persons engaged (thousands)
Electrical machinery	51 086 (17.8%)	1 819 (17.5%)
Transportation machinery	42 011 (14.8%)	908 (8.3%)
Industrial machinery	29 758 (10.1%)	1 147 (10.5%)
Chemicals	22 189 (7.4%)	393 (3.6%)
Food	21 939 (7.3%)	1 081 (9.9%)
Iron and steel	17 239 (5.8%)	336 (3.1%)
Manufacturers total	298 877 (100%)	10 962 (100%)

Source: Ministry of International Trade and Industry (MITI). Urgent Report of Industrial Statistics.

Table A.2. Transition of the export and import of chemical products
(Millions of US dollars)

	1985	1986	1987	1988	1989	1990
Export	7 698	9 484	11 662	13 964	14 776	15 872
	(0.9)	(23.2)	(23.0)	(19.7)	(5.8)	(7.4)
Import	8 073	9 733	11 845	14 830	15 948	16 045
	(-3.3)	(20.6)	(21.7)	(25.2)	(7.5)	(0.6)
Deficit	375	249	183	866	1 172	173

Source: Ministry of Finance.

Note: Figures in parentheses denote the percentage change over the previous year.

Table A.3. Export and import of chemical products in the regional market
(Hundreds of millions of US dollars)

		1987	1988	1989
United States	Export	2 081	2 291	2 524
	Import	4 035	4 629	5 208
European Community	Export	1 792	2 270	2 390
	Import	3 873	5 000	4 968
South-East Asia	Export	5 259	6 546	7 088
	Import	1 147	1 488	1 766

Source: MITI, White-Paper of International Trade of Japan.

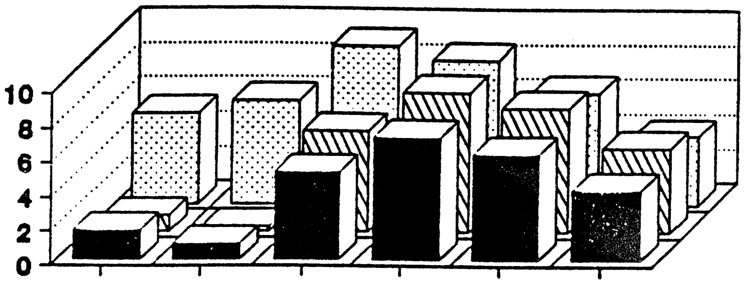
Table A.4. Trend in investment by chemical industries in plants and equipment

	1988	1989	1990 performance estimation	1991 (plan)
Chemical industry	29.4	19.8	27.9	-24.2
Investment per year manufacturers total	27.3	24.2	25.7	-2.3

Source: MITI Survey (September 1990).

Note: All figures denote growth rates over previous year.

Figure. Transition of the growth rate of industries production



	1985	1986	1987	1988	1989	1990
Fabricating	5.3	6	9.2	8.4	6.5	4
Commodity etc	1	0.3	5.9	8.2	7.3	6
Chemical Industry	1.8	1	5.2	7.2	6.3	4.2

Chemical Industry   Commodity etc
Fabricating

Source: MITI.

Table A.5. Share of investment in plants and equipment of chemical industry in viewpoint of management purpose
(Percentage)

	1990 performance estimation	1991 plan
Investment related to the actual production	46.6	42.4
Maintenance and preparation	11.9	11.1
Investment for replacement	5.9	7.1
Investment for rationalization and labour-saving	8.3	12.3
Investment for R & D	9.2	12.2
Investment for prevention of public pollution, energy-saving	3.4	2.0
Others	14.7	12.8

Source: MITI Survey (September 1990).

Table A.6. Trend in domestic wholesale prices and output-input index of chemical products

(100 in 1985)

	Wholesale prices					
	1985	1986	1987	1988	1989	1990
Chemical products	100.0 (-1.9)	93.5 (-6.5)	90.1 (-3.6)	89.9 (-0.2)	91.4 (1.7)	92.5 (1.2)
FYI grand total	100.0 (-8.9)	95.3 (-4.7)	92.3 (-3.1)	91.9 (-0.4)	93.6 (1.8)	95.0 (1.5)

	Output-input index of chemical products					
			1990			
	1989	1990	Jan-Mar	Apr-Jun	Jun-Sep	Oct-Dec
Input prices (Index A)	(8.1) (2.4)	85.1 (4.9)	81.9 (0.9)	82.6 (0.9)	84.4 (2.2)	91.3 (8.2)
Output prices (Index B)	89.4 (1.8)	90.1 (1.7)	90.1 (0.2)	90.1 (0.2)	90.2 (0.1)	93.3 (3.4)
Index of terms of trade (B/A)	110.2	106.8	110.0	109.1	106.9	102.2

Source: The Bank of Japan "Annual Report of Prices Index".

Note: The figures in parentheses denote the percentage change over the previous year/quarter.

The supply-demand position in Japanese petrochemicals is bound to the developments in the rest of East Asia. Several new plants and expansions of existing plants are coming on stream in the Republic of Korea and other economies in the region. Following the liberalization of investment in petrochemicals in April 1990 in the Republic of Korea, several plans for new facilities were announced (see annex II). Although the Gulf war and the subsequent situation regarding availability and prices of raw materials may prevent all six major plans from being realized, a major transformation of the petrochemicals market is under way throughout the region, with several nations building capacity to meet domestic demand and export to regional markets.

Japanese plans for adding new ethylene capacity and upgrading existing facilities are being evaluated in the light of these changes in the supply/demand balance of the region. An important consideration is to maintain international competitiveness, but this is tempered by considerations regarding security and cost of raw materials. In this connection, plans to expand

and add to existing ethylene facilities are being seriously considered in order to technologically upgrade and enlarge production capacity to ensure international competitiveness. On the other hand, the Gulf war has necessitated even greater caution in evaluating risky large-scale investments in petrochemicals. Nevertheless, major changes are under way in East Asian petrochemicals, a region which was hitherto traditionally dependent on imports from the Middle East and North America.

Table A.7. Income and profit of the chemical industry
(Hundreds of millions of yen)

	Oct-Dec 1989	Jan-Mar 1990	Apr-Jun 1990	July-Sep 1990	Jan-Sep 1990
Sales amounts	83 852	78 920	84 167	85 162	284 249
	(7.8)	(3.6)	(10.5)	(6.8)	(7.0)
Ordinary profit	7 408	5 156	7 060	5 428	17 644
	(10.7)	(-14.0)	(9.1)	(-9.6)	(-4.5)_
Ordinary profit rate of sales	8.8	6.5	8.4	6.4	7.1

Source: Japan, Ministry of Finance, "Quarterly review of the corporation statistics" (*sic*).

Note: The figures in parentheses denote the percentage change over the previous quarter or term.

Table A.8. Trend in the income and profit of the chemical industry
(Percentage change on annual basis)

	1985	1986	1987	1988	1989	1990
Sales amounts	1.5	-8.5	4.9	8.4	5.3	7.7
Operating profit	-6.1	-1.9	20.9	14.2	-3.8	-
Ordinary profit	-2.2	3.5	30.9	21.2	2.5	-8.1
Ordinary profit rate of sales	5.59	6.33	7.90	8.85	8.61	-

Source: The Bank of Japan, "The Management of Analysis of the Main Enterprises" (*sic*).

Note: The figures for 1990 are estimates from the survey of the Bank of Japan.

C. THE SUPPLY OF NEW MATERIALS FOR THE PETROCHEMICALS INDUSTRY

A central characteristic of the Japanese petrochemicals industry is the near-100% dependence on overseas sources of feedstock materials, namely naphtha. Naphtha is either imported (about 78%) directly into Japan or produced domestically from imported crude oil. There again, Japan is almost entirely dependent on crude-oil imports from abroad. The Gulf war spawned a rapid increase in the price of naphtha with profound implications for obtainment of sufficient quantities of naphtha (16% comes from the Middle East) and the cost structure of domestic industry. In addition, Japan lost its crude oil and oil-product supplies from Kuwait and Iraq. The upward movement of raw-material prices, together with rising interest rates, depreciation and wage costs, exerted downward pressures on corporate earnings throughout 1990 and 1991. These developments have sharply highlighted the need for the Japanese petrochemicals industry to reduce its total reliance on naphtha, which, in turn, is highly dependent on Middle East sources of supply. The reduction of dependence on naphtha, together with a diversification of sources of supply, now has urgent technological and organizational priority for the petrochemicals industry.

D. R&D TRENDS AND DIRECTIONS

An examination of trends in the composition of capital expenditures over the last decade,[3] reveals an increased emphasis on R&D, especially after the adverse economic circumstances of the mid-1980s. R&D investment in the chemicals industry grew on average by 10% per annum during the 1980s.

R&D expenditures comprised nearly 3% of total capital investment in the industry in 1976, 10% in 1979, 17.9% in 1987, 16.5% in 1988, and were estimated at 15.1% in 1989, 9.2% in 1990 and 12.2% in 1991. The ratio of R&D expenditures over sales increased throughout the last decade, remaining on average one to two percentage points above the average for all manufacturing industries. Overall, the evidence suggests that for several years now the industry has been exerting concerted efforts to strengthen its research and development capabilities and improve both production technologies and knowledge intensity of products. The proportion of R&D expenditures allocated to basic research rose to over 10% of the total by the mid-1980s and continued to increase thereafter. This is in line with the rapidly increasing importance of fundamental research for successful innovation in chemicals.

E. MANAGEMENT STRATEGIES INTO THE 1990S

The industry is undergoing a fundamental structural change, which is reflected in the medium-to long-term management strategies devised for the 1990s. There is a pronounced shift already under way, since the late 1980s, towards the production of research- and knowledge-intensive fine chemicals aimed at high-growth market segments, as Japanese industry shifts to technically demanding and sophisticated products and processes. This is expected to accelerate through the beginning of the next century, together with aggressive efforts to strengthen the pure and applied research base of the chemicals corporations. A parallel, and in some respects necessary, aspect of this is the concerted efforts to globalize the industry and transform the relatively small Japanese firms, in comparison with the European and American giants, into large, multinational chemical corporations able to compete in the world market. A chosen method of internationalizing operations is via friendly acquisitions of chemical firms, especially in the United States and Europe. This enables Japanese firms to establish a presence in markets abroad and/or strengthen their technology base and diversify into new, high-growth,

[3] Japan Development Bank and Japan Chemical Industry Association, Annual Reports 1987-1988, and 1989-1990.

fine-chemicals products. The move abroad is also closely related to establishing a supply base in close physical proximity to Japanese transplants abroad.

F. THE FUSION OF CHEMICALS INDUSTRY WITH NEW MATERIALS, MICRO-ELECTRONICS AND BIOTECHNOLOGIES

Japanese chemical corporations are acutely aware that new materials, micro-electronics and biotechnologies are fast becoming the major technology drivers for Japanese industry, the chemical industry in particular, leading to the creation of massive new markets in the next century. The chemicals industry already interfaces with several technologies in other fields and is expected to provide key technologies and materials for advances to be made in these fields. As Yuichiro Kasawa, Chairman of Mitsui Toatsu Chemicals, put it at the Second International New-Chemistry Symposium (Tokyo, October 1989), "With the age of new chemistry approaching, chemistry has become a key technology as we move towards the 21st century. Chemistry is also expected to play a vital role in the future development of advanced technology industries".[4] New chemistry is seen to comprise vital technologies expected to yield new business opportunities through combinations and gradual mergers with other scientific and engineering fields. It is expected to provide a core technology for frontier industry innovation. Progress depends on stepping up basic research and closer cooperation between industry, Government and academia. It involves exchange of information, collaboration, and tie-ups between different sectors, and protection of intellectual property rights in R&D breakthroughs. Whether the present chemical industry can keep pace with new-chemistry developments depends on drastic technological reforms through basic research requiring large sums, long gestation periods and superior research personnel.

In micro-electronics, for example, the chemicals industry provides critically important materials for electronic devices, such as compound semi-conductors, materials for recording and memory devices, liquid crystal displays, materials for opto-electronics and so on. Other new materials also emerging from the chemicals industry include high-performance polymers, new functional and structural materials, such as fine ceramics, new metallic substances, and pharmaceutical and agricultural chemicals through biotechnology or protein engineering.

Together with moving downstream and getting close to the customer in the development of chemical specialties, chemical firms are diversifying into fine chemicals and new materials. Already the evidence points to the fact that approximately half of the total R&D outlays of chemical and synthetic-fibre industries is spent on their original business and the other half in other fields, and this is indicative of the overall trends. Chemical firms are acquiring multi-materials capabilities together with a multidisciplinary research competence in line with developments and requirements of the materials-producing and -using industries. At the same time that the chemical industry is moving into the development and production of advanced polymers and diversifies into other new materials, pharmaceuticals and biotechnologies, firms from a diverse number of fields have also diversified aggressively into new and related fields. This process, whereby corporations in traditional lines of business increasingly interpenetrate into new materials fields and diversify into major new technologies with high growth potential, is leading to an intensification of the competitive pressures experienced

[4] *Japan Chemical Week*, 9 November 1989.

throughout industry and not merely by chemicals corporations. In these circumstances, not only does R&D acquire crucial significance, but it also involves the complex interfacing of several technologies, research fields and disciplines in all the physical and life sciences.

Recognizing the importance of the chemicals industry for technical progress in several major fields, the Government is promoting collaborative mechanisms among industry, government institutions and academic circles in order to conduct effective R&D. Thus, chemicals technologies are forming a basic part of the 13 themes chosen under AIST's Basic Technologies of Future Industries, in new materials, functional devices and biotechnology. Other government-supported programmes of relevance to the chemicals industry involve those promoted by the reorganized New Energy and Industrial Technology Organization (NEDO), the ERATO system, and the funding programmes of the Centre for Research Facilitation in Fundamental Technologies.

Health, safety and the environment present a major concern for the industry. Consequently, the industry established the "Guiding Principle for the Improvement on Environment, Health and Safety of the Japan Chemical Industry Association" in November 1990 in order to confront new aspects of problems relating to global environmental issues, waste treatment and safety issues related to chemical-product liability.

Annex II

CHEMICALS AND PETROCHEMICALS IN THE REPUBLIC OF KOREA

Over the last three decades, the chemicals industry of the Republic of Korea has grown from virtual non-existence in the early 1960s, to large-scale production and growth in the 1980s. In the late 1960s, the Government of the Republic of Korea put considerable emphasis on the development of chemicals technology. The first synthetic resin to be produced was PVC in 1967, followed by PE and PPE in 1972, but the industry was badly shaken by the oil shocks of 1973 and 1979. Nevertheless, the industry grew rapidly in the 1980s, moving from commodity-resins production (PVC, HDPE, PP and PS) towards higher-value-added materials, engineering plastics and an increasing effort towards the development of advanced polymeric materials such as high-function polymers, specialty polymers, liquid crystals and biopolymers.

Since the early 1970s, there have been two major petrochemical complexes, the largest at Ulsan, where Yukong also has an aromatics unit producing 800,000 tonnes per year of benzene, toluene and xylene, and has completed an expansion programme lifting its ethylene production from 155,000 to 555,000 tonnes per year. The smaller Yeocheon complex is in South Colla Province, where the Daelim Industrial Company's ethylene output of 700,000 tonnes per year supplies 10 companies downstream. A third complex is currently under way at Sosan, where Samsung General Chemical is building a Greenfield integrated complex costing $1.5 billion and containing a 350,000-ton naphtha cracker and facilities for LDPE, linear-LDPE, HDPE, polypropylene, styrene monomer and EG. Similarly, Hyundai Petrochemical is building a $1.5 billion complex at Sosan, comprising a 350,000-ton-per-year cracker and an olefin complex, producing derivatives such as LDPE, linear-LDPE, polypropylene, HDPE, EG, styrene monomer, butadiene and caprolactam.

The expansion of naphtha-cracking capacity will raise output from 1.1 million tonnes (E-base) per annum to over 3 million tonnes per annum in 1992 (tables B.1 and B.2). While in early years the Government prevented vertical integration in order to avoid the dominance of one firm over the whole industry, the recent liberalization measures have brought on a spate of efforts by downstream companies to integrate backwards, thus competing head-on with their former feedstock suppliers Yukong and Daelim. On the other hand, ethylene producers (Yukong, Daelim and oil refiner Honam) are moving downstream into intermediates and commodity plastics.

Tables B.3, B.4 and B.5 show the expansion plans and the rapid growth envisioned for polyethylene, polypropylene and polystyrene and its copolymers. As the demand for engineering plastics has been rising, the industry's attention has been caught; a number of companies are planning the manufacture of engineering plastics (tables B.6 and B.7), and more are expected to join in. Elastomer production is keeping pace with resin production and will rise to 515,000 tonnes per year by 1992 (table B.8). Expansion of compounding facilities is presented in table B.9.

In polymer production, the Republic of Korea is advancing on two fronts. The first is to expand the production of commodity plastics, man-made fibres and synthetic rubbers for mass consumption. This process is well under way and will be completed by the mid 1990s.

The second is to utilize advanced technologies to produce higher-value-added and new polymers. This is considerably more difficult and requires the involvement and collaboration of industry, university, and government research centre (in this case consortia such as the newly formed National Engineering Research Centre for New Materials). In addition, technological upgrading and the move to specialties and engineering polymers involve the participation of foreign companies in the chemical industry of the Republic of Korea (table B.10), and this is encouraged. Production facilities for petrochemicals in the Republic of Korea by company are given in table B.11.

FINE CHEMICALS

With over 1,000 companies, the industry is highly fragmented. Forty per cent of the total number employ less than 20 persons, and only 43 firms (4.6%) employ over 300 persons. The output of the industry is aimed at the domestic market, which accounts for 95% of domestic production. Nevertheless, excessive reliance on the domestic market may hamper its growth and development, given the lack of appropriate downstream industries to absorb a greater variety of high-value-added products. While Japanese industries use around 40,000 types of chemicals, and Germany, Switzerland and the United States about 60,000-70,000, the Republic of Korea consumes only 10,000 different kinds of fine chemicals. In terms of exports, after rising by 20% in 1988, the growth rate dropped to 5% in 1989, a major reason being the appreciation of the won, which eliminated the price competitiveness of fine chemicals from the Republic of Korea in the world market. Forecasts for exports, imports and production are given in table B.12.

The small or medium size of most firms is an obstacle to innovation in an industry characterized by knowledge-intensive, high-value-added products. The R&D spending of domestic companies is much lower than that of major foreign companies (table B.13). R&D spending by 170 firms in the Republic of Korea constituted 1.6% of sales in 1986, and this rose to only 1.9% in 1988. Moreover, the sector displays heavy reliance on foreign technology, with 385 cases of technology transfer recorded from 1962 to mid-1989, where paints and pharmaceuticals accounted for 31.9% and 23.9% respectively.

THE KOREAN RESEARCH INSTITUTE OF CHEMICAL TECHNOLOGY (KRICT)

KRICT engages in contract research; thus, research programmes and direction are heavily influenced by industry requirements. The Institute tries to keep 3-5 years ahead of industry, since if research is much more long-term oriented, industry would simply not be interested. There are some 300 domestic firms that retain close links with the Institute. Domestic chemical companies provided nearly two thirds of its funds before 1987, but government funding has now increased.

Table B.1. Major petrochemicals and polymers in the Republic of Korea
(Thousands of tonnes per year)

	Capacity				Demand		
Item	Existing	Expansion	Planning	Total	1990	1993	1995
Ethylene	1 155	950	1 100	3 205	1 516	1 894	2 193
Propylene	388	240	970	1 598	1 008	1 233	1 386
SM	237	765	220	1 222	711	918	1 089
VCM	210	450	-	660	501	623	716
AN	52	37	90	179	244	268	284
TPA	500	460	-	960	897	1 162	1 368
EG	80	200	180	460	410	509	589
PA	105	30	100	235	104	132	154
LDPE	200	110	610	920	425	519	591
HDPE	45	-	360	810	399	509	597
PP	660	50	1 040	1 750	579	724	838
PS	779	60	95	934	362	471	562
PVC	550	150	-	700	495	616	708
SBR	150	50	92	292	132	159	180
BR	95	-	20	115	69	95	118
ABS	225	90	55	400	66	90	106

Source: KIST.

Table B.2 Oil refining capacity
(Thousands of barrels per year)

Company	Existing	Expansion	Site
Yu Kong	280	95	Ulsan
Honam	380	-	Yeocheon
Saangyong	60	10	Onsan
Kyung In	60	40	Inchon
Kuk Dong	60	100 (1992)	Dacsan

Source: Republic of Korea, Ministry of Science and Technology.

Table B.3. Polyethylene production in the Republic of Korea
(Thousands of tonnes per year)

Company	Existing	Expansion[a]	New project[a]	Remarks
Hanyang Chem.	200	110 (91)	80 (90)	LLD, LD, HD (new)
Honam Petr.	180			HD
Korea Petr.				HD
Lucky			120 (6/92)	VLD, LLD, LD
Yu Kong			200 (90)	LLD, HD
Samsung Gen.			260 (92)	LD, HD
Hyundai Petr.			260 (92)	LLD, LD, HD
Daelim Ind.			180 (91)	HD
Dongbu Petr.			120	
Total capacity (1992); 1,980,000 tonnes				

Source: Republic of Korea, Ministry of Science and Technology.

[a] Figures in parentheses indicate the (month and) year that the project came on stream.

Table B.4. Polypropylene production in the Republic of Korea
(Thousands of tonnes per year)

Company	Existing	Expansion	New project[a]	Remarks
Honan oil	120	-	-	LPG
Korea Petr.	350	-	-	-
Honam Petr.	190	50 (90)	-	-
Yu Kong	-	-	100 (90)	-
Samsung Gen.	-	-	170 (92)	-
Hyundai Petr.	-	-	170 (92)	-
Hangyang Chem.	-	-	120 (92)	-
Daelim Ind.	-	-	60 (91)	-
Isu Chem.	-	-	250 (90.9)	LPG
Tongyang Nylon	-	-	80 (90.6)	-
Dongbu Petr.	-	-	90	-

Total capacity (1992); 1,750,000 tonnes

Source: Republic of Korea, Ministry of Science and Technology.

[a] Figures in parentheses indicate the (month and) year that the project came on stream.

The 600-strong KRICT, with an annual budget of W 20 billion (about $30 million) per year, is playing a critical and catalytic role in the transition of the chemicals industry in the Republic of Korea from the role of technology importer and learner to that of originator and developer, especially given the 1987 extension of patent protection to the chemical process. Although the annual budget of the Institute is less than one twentieth of the annual R&D expenditures of chemical giants in Europe and the United States, the quality of the research conducted at KRICT rivals foreign results. The central aim is to assist industry in the Republic of Korea to begin the process of independent development of new materials, compounds and technologies, doing away with the excessive reliance on foreign-technology transfers and alliances with foreign firms which, although important, carry severe limitations in conferring technology-based competitive advantage to local chemicals companies.

Given the importance of advanced materials in the Government's thinking, KRICT is called upon to play a central role in filling the existing gap in advanced-materials research, production and use in industry. But the development of new materials must fit into existing industry (for example, there are, as yet, no great prospects in aerospace), or they can be licensed abroad, where foreign companies will be able to innovate through their use.

New materials enter into complex engineering "systems" which combine materials and electronics hardware and software. Japan has hitherto provided the key components (e.g., engine parts) and/or electronic "black box" technologies, which are then used in assemblies and sold. Unless the Republic of Korea is able to produce the "black box" itself, the country will be unable to apply and commercialize new advanced materials. Hence, one can conceive of a sequential approach in which the "black box" system comes first, followed by imports of new materials and the development of markets for them, and finally domestic advanced-materials production itself.

Table B.5. Polyethylene production in the Republic of Korea
(Thousands of tonnes per year)

Company	Resin	Existing	Expansion	New project
Lucky	PS	90	-	-
	EPS	20	10 (90)[a]	-
	ABS	135	30 (90)	-
	SAN	60	-	-
Hannam Chem.	PS	147	-	-
	EPS	64	-	-
	ABS	90	-	-
Hyosung BASF	PS	135	-	-
	EPS	55	-	-
	ABS	-	-	25 (90)
	SAN	-	-	5 (90)
Shin-A Chem.	PS	100	-	-
	EPS	18	-	-
	ABS	30	-	-
Yu Kong	PS	-	-	90 (90)
	ABS	-	-	30 (90)
Cheil Ind.	PS	90	-	-
	ABS	-	60 (91)	-
Dongbu Petr.	PS	-	50 (90)	-
Total capacity (1991):	PS:	702,000		
	EPS:	167,000		
	ABS:	400,000		
	SAN:	65,000		
Grand total		1,334,000		

Source: Republic of Korea, Ministry of Science and Technology.

[a] Figures in parentheses indicate the year that the project came on stream.

Table B.6. PVC and PMMA production in the Republic of Korea
(Thousands of tonnes per year)

Resin	Company	Existing	Expansion[a]	New project[a]	Remarks
PVC	Lucky	300	-	-	-
	Hanyang Chem.	250	150 (91)	-	-
PMMA	Lucky	10	10 (90)	-	Zimmar
	Cheil Ind.	-	-	15 (90)	Mitsubishi
	Hanyang Chem.	-	-	12 (92)	PTI (USA)
	Hannam Chem.	-	-	15 (92)	PTI (USA)

Source: Republic of Korea, Ministry of Science and Technology.

[a] Figures in parentheses indicate the year that the project came on stream.

Table B.7. PC, POM and PPO production in the Republic of Korea
(Thousands of tonnes per year)

Resin	Company	Existing	New project[a]	Foreign participation
PC	Lucky	-	20 (6/90)	GE
	Kumho Sinvet	-	15 (91)	EniChem (Italy)
	Samyang	-	15 (6/90)	Mitsubishi Gas
POM	Lucky	10	-	-
	Kumho Petr.	-	10	-
	Korea Eng. Plas.	10	10 (5/90)	Mitsubishi Gas
	Kohap Chem.	-	-	-
	Yujin Chem.	-	15 (90)	-
	DuPont Korea	10	-	-
PPO	Lucky	-	-	-

Source: Republic of Korea, Ministry of Science and Technology.

[a] Figures in parentheses indicate the (month and) year that the project came on stream.

Table B.8. Elastomer production in the Republic of Korea
(Thousands of tonnes per year)

Company	Resin	Existing	Expansion[a]	New project[a]	Foreign participation
Kumho Petro	SBR	150	50 (90)	-	-
	BR	95	-	-	-
	HSR	5	-	-	-
	NBR	5	-	-	-
	SB Latex	40	-	-	-
Kumho EP	EPR	13	10	-	-
Yu Kong Elastomer	EPR	-	-	20 (12/91)	YK/Sumitomo (70%/30%)
Hyundai Petro.	SBR	-	-	52 (92)	-
Daelin Ind.	SBR	-	-	40	-
	BR	-	-	20	-
Ulsan Pacific Chem.	SB Latex	-	-	12 (90)	UTT/Dow

Source: Republic of Korea, Ministry of Science and Technology.

[a] Figures in parentheses indicate the (month and) year that the project came on stream.

Table B.9. Compounding facilities in the Republic of Korea
(Thousands of tonnes per year)

Company	Existing	Expansion[a]	New project[a]	Main resin
Lucky	17	-	-	Engineering grade
Lucky Allied	-	-	10/10 (90/94)	Nylon, PET
Cheil Synthetic Fib.	1.3	-	-	PBT
Tongyang Nylon			-	Nylon, PC, PBT
Hyosung BASF			-	PPO
Korea Eng. Plas.	10	10 (5/90)		POM
DuPont Korea			10	POM

Source: Republic of Korea, Ministry of Science and Technology.

[a] Figures in parentheses indicate the (month and) year that the project came on stream.

KRICT certainly is aware of such factors but cannot put all its effort into this area. There are, in fact, other priorities as well, and considerable research effort is going into conventional polymers. If all of the much-discussed expansion in ethylene capacity comes onstream, capacity will be raised from 1.15 million tonnes in 1990, to 3.3 million in 1993, while domestic demand is only projected to rise from 925,000 tonnes per year to less than 1.9 million tonnes by the year 2000. There is therefore a massive over- capacity in basic petrochemical feedstock (used in plastics, and synthetic fibres) under way, which is a cause of major concern in the region. Given this, companies are trying to increase export of plastics, fibres and resins within the region, including the vast Chinese market, as well as enter into agreements with Japanese chemical companies. There exists therefore a good research basis for polymers. The Republic of Korea must export either petrochemicals to the region or higher-value-added chemicals. There is an increasing interest in placing more emphasis on specialties and advanced- polymer materials, and the Government is so convinced of its importance that it has included it in a national project. Both KRICT and industry are therefore working on research programmes aimed at replacing commodity chemicals with fine chemicals, specialties, and engineering polymers and composites. A major problem in developing advanced materials, however, is the very small market that currently exists in the Republic of Korea for such materials.

Table B.10. Foreign companies in the Republic of Korea
(Thousands of tonnes per year)

Company	Country	Name used in the Republic of Korea	Business	Foreign participation
BASF	Germany	Hyosung BASF	Styrenics	
Hoechst	Germany	Hoechst Ind.	PCB, PET film	
BP	Great Britain	Samsung BP	Acetic acid	SS/BP=49/51%
ICI	Great Britain	ICI Woobang	Surfactants	
Solvay & Cie	Belgium	Hanyang materials	Plastic panels	
EniChem	Italy	Kumho Sinvet	PC	KH/EC=50/50%
Arco	USA	Yu Kong Arco	PO, SM	
Allied-Signal	USA	Lucky Allied	Nylon, PET Comp.	L/AS=50/50%
Dow	USA	Ulsan Pacific Chem.	SB Latex	
DuPont	USA	DuPont Polymer	EP Comp	100% DuPont
DuPont	USA	DuPont specialty Polymer	PVB	100% DuPont
GE	USA	Lucky Ltd.	PC	
Monsanto	USA	Kumho Monsanto	Rubber additives	
Mitsubishi Gas	Japan	Korea Eng. Plastics	POM Comp.	
Sumitomo	Japan	Yu Kong Elastomer	EPR	YK/S=70/30%

Source: Republic of Korea, Ministry of Science and Technology.

Table B.11. Production facilities for petrochemicals in the Republic of Korea

Company	Item	Existing	Expansion[a]	New Project[a]	Site
		LUCKY GROUP			
Honam Oil Refinery	Benzene			100 (90)	Yeocheon
	Toluene			60 (90)	
	Xylene			100 (90)	
	p-Xylene			200 (90)	
	PP	120			
Lucky Ltd.	Acrylates	35	41 (89)		Najoo
	Butanol	17.5	14 (89)		
	Octanol	55	44 (89)		
	IPA			30 (12/90)	
	DOP	105			
	LDPE			120 (12/89)	
					Yeocheon
	PVC	300			
	PS	60	30 (4/89)		
	EPS	20	10 (90)		
	ABS	135	30 (90)		
	SAN	50	30 (11/89)		
	PMMA	10	10 (90)		
	PBT	3	2 (89)		
	PC		20 (6/90)		
	POM	10			
	PPO				
	Epoxy	5			
	EP Comp.	10.5			
	GF	8	6.5 (89)		
			5 (89)		
Lucky Petrochemicals	Naphtha			350 (6/91)	Yeocheon
	Ethylene			350 (6/91)	
	Propylene			171 (6/91	
	Butadiene			34 (6/91)	

Table B.11. (*continued*)

Company	Item	Existing	Expansion[a]	New Project[a]	Site
	LUCKY GROUP				
Lucky Polychemicals	SM			300 (3/90)	Yeocheon
	PA			40 (12/90)	
Lucky Advanced Materials	VCM			300 (3/90)	Yeocheon
	Carbon black 94				
	TiO			30 (89)	
Lucky Allied	Nylon Comp			10/10	
	PET			(90/94)	
	HYUNDAI GROUP				
Hyundai Petrochemicals	Naphtha			400 (93)	Daesan
	Ethylene			358 (93)	
	Propylene			175 (93)	
	Butadiene			51 (93)	
	Benzene			130 (93)	
	Caprolactam			72 (93)	
	EG			100 (93)	
	MTBE			40 (93)	
	SM			? (93)	
	LLDPE			100 (93)	
	LDPE			100 (93)	
	HDPEPR			60 (93)	
	SBR			170 (93)	

Table B.11. (*continued*)

Company	Item	Existing	Expansion[a]	New Project[a]	Site
		SUN KYONG GROUP			
Yu Kong	Naphtha	155	400 (9/89)		Ulsan
	Ethylene	144	400 (9/89)		
	Propylene	81	212 (9/89)		
	Butadiene	24	73 (9/89)		
	Benzene	194	53 (9/89)		
	Toluene	270	40 (9/89)		
	Xylene	297	47 (9/89)		
	o-Xylene			50 (9/89)	
	p-Xylene			200 (9/89)	
	Cyclohexane	40	100 (9/89)		
	MTBE			80 (9/89)	
	Butene-1			30 (89)	
	MMA			30	
	MEK			50 (12/91)	
	IPA			35 (12/91)	
	LLDPE			80 (89)	
	HDPE			120 (89)	
	PP			100 (89)	
	PS			90 (89)	
	ABS			30 (89)	
				30 (89)	
Yu Kong-Arco	SM			225 (4/90)	Ulsan
	PO			100 (4/90)	
	PG			25 (90)	
	PPG			20 (3/90)	
SKI	TPA			160 (9/89)	Ulsan
	DMT			100 (89)	
Yu Kong Elastomer	EPR		20 (12/91)	Yu Kong/ Sumitomo= 70/30%	Ulsan

Table B.11. *(continued)*

Company	Item	Existing	Expansion[a]	New Project[a]	Site
		SAMSUNG GROUP			
Samsung Petrochemical	TPA	500	100 (120/89		Ulsan
Samsung General Chemical	Naphtha			350 (92)	Daesan
	Ethylene			350 (92)	
	Propylene			175 (92)	
	Butadiene			40 (92)	
	Benzene			130 (92)	
	Toluene				
	p-Xylene				
	Acetic Acid				
	SM			180 (92)	
	EG			100 (92)	
	LDPE			140 (92)	
	HDPE			120 (92)	
	PP			170 (92)	
Cheil Industry	PS			90 (6/89)	Yeocheon
	ABS			30/30 (6/89)	
	PMMA			15 (89)	
Cheil Synthetic Fibres	Expoxy	21	18 (12/89)	7	
	Base film				
	Photo resin				
	FR-PBT	1.3			
Samsung BP	Acetic acid			150 (12/91)	

Table B.11. (*continued*)

Company	Item	Existing	Expansion[a]	New Project[a]	Site
		KOREA EXPLOSIVES GROUP			
Hang Yang Chemical	Naphtha			350 (8/91)	Yeocheon
	Ethylene			350 (8/91)	
	Propylene			150 (8/91)	
	Butadiene			45 (8/91)	
	BTX			163 (8/91)	
	CI	210	110 (92)		
	VCM	210	150 (6/90)		
	EDC	286	150 (91)		459
	HCI(100%)	25			
	NaOH	227	120 (7/91)		Chinhae
	ECH			20 (12/91)	Chinhae
	DOP	30	20 (91)		Chinhae
	LLDPE	80	113 (10/91)		
	LDPE	223			
	HDPE			80 (89)	
	PP			120 (3/92)	
	PVC	250	150 (91)		Chinhae
	PMMA			12 (92)	
	TiO			60	Yeocheon
Han Yang BASF	MDI		40 (91)		
	Aniline		40 (92)		
Korea Explosives	Nitrobenzene	5			
Kyung in Energy	Benzene			80	1,400
	Toluene			100	
	Xylene			170	

Table B.11. *(continued)*

Company	Item	Existing	Expansion[a]	New Project[a]	Site
		KUMHO GROUP			
Kumho Petro-chemicals	Butadiene	70	35 (89)		Yeocheon
	Butene-1			10	
	Cl_2			50 (92)	
	NaOH			50 (91)	
	ECH			15 (92)	
	SM			120	
	MMA			16	
	SBR	150	50 (90)		Ulsan
	SB Latex	20	20 (89)		Ulsan
	BR	35	60 (89)		Yeocheon
	HSR	5			
	NBR	5			
	POM			10	
Kumho EP Rubber	EPR	13		10	Yeocheon
Kumho Shell	Phenol	30	70 (90)		Yeocheon
	Aceton	18	42 (90)		
	MIBK			12 (12/89)	
	BPA			25 (12/89)	
	MEK			50 (91)	
	Epoxy			8 (90)	
Kumho Sinvet	PC			15 (91)	Yeocheon
Kumho Mitsui Toatsu	MDI			40 (6/91)	Yeocheon

Table B.11. (*continued*)

Company	Item	Existing	Expansion[a]	New Project[a]	Site
		DAELIM GROUP			
Daelim Ind.	Naphtha	350	250 (89)		
	Ethylene	350			
	Propylene	187	145 (89)		
	Mixed C_4	128	98 (89)		
	Benzene	85	66 (89)		
	Toluene	22	34 (89)		
	Xylene	41	25 (89)		
	Butene-1			20	
	Isobutylene				
	MTBE			96	
	SM	80	120 (89.10)		
	AM			60 (94)	
	Caprolactam			100 (94)	
	HDPE			120/60 (89)	
	PP			60 (12/91)	
	SBR			40	
	BR			20	
		DAEWOO GROUP			
Isu Chemical	Propylene			250 (12/90)	Onsan
	MMA			50	
	Alkyl				
	Benzene	140	20		
	n-Paraffin			100 (12/89)	Onsan

Table B.11. (*continued*)

Company	Item	Existing	Expansion[a]	New Project[a]	Site
		LOTTE GROUP			
Honam Petrochemical	Naphtha			350 (6/92)	Yeocheon
	Ethylene			350 (6/92)	
	Propylene			190 (6/92)	
	BTX			153 (6/92)	
	Butadiene			56 (6/92)	
	SM			120	
	MMA			20 (92)	
	EG	80	120 (92)		
	EO	72	108 (92)		
	HDPE	130	50 (89)		
	PP	190	50 (89)		
		POHANG STEEL			
Korea Steel Chemical	Carbon black	90	30 (6/89)		Pohang
	PA	30	30 (90)		
	Phenol	1.5			
	Benzene	30	20		
	Naphthalene	25			
	H-acid			? (6/89)	
		HYOSUNG GROUP			
Tongyang Caprolactam	Propylene			150 (6/90)	Ulsan Nylon
			100 (90)		
	Nylon	130			
	PP			80 (6/90)	
	Comp				

Table B.11. (*continued*)

Company	Item	Existing	Expansion[a]	New Project[a]	Site
		HYOSUNG GROUP (continued)			
Hyosung 25	PS	60	75 (4/89)		Ulsan BASFEPS 30
	ABS			25 (10/89)	
	SAN			5 (10/89)	
	PPE Comp				
Korea Eng.	POM	10	10 (5/90)		Plastics
Korea Petrochemical Industry	Naphtha			250 (12/90)	Ulsan
	Ethylene			250 (12/90)	
	Propylene			148 (12/90)	
	Mixed C			98 (12/90)	
	HDPE	150	120 (89)		
	PP	350			
Dongbu Petrochemical	Naphtha			250	Ulsan
	Ethylene			250	
	Propylene				
	Butadiene			30	
	Isobutylene			17	
	EG			80	
	IPA			40	
	SM	110	100 (3/90)		
	PE			120	
	PP			90	
	PS			50 (89)	
Hannam Chemical	PPG	20	20 (2/90)		
	PS	147			
	EPS	64			
	ABS	70	20 (89)		
	PMMA			15 (89)	
Miwon	PPG	10			

Table B.11. *(continued)*

Company	Item	Existing	Expansion[a]	New Project[a]	Site
		HYOSUNG GROUP (continued)			
Shin-A-Chemical	PS	63	37		Kunsan
	EPS	18			
	ABS	15	15 (2/89)		
Kohap	Benzene	30	46 (89)		
	o-Xylene	60			
	p-Xylene	160	100 (89)		
	TPA			100 (12/89)	
	POM				
Tong Suh Petrochemical	AN	52	37 (89)		
Korea Polyol	PPG	40	10 (89)		
	EOA	5			
	PEG	1			
Sam Kyung Chemical	MA	3			
	DA	70	30 (89)		
	DOP	50	20 (88)		
Dainong Petrochemical	MA	12	5 (89)		
Hankook Caprolactam	Caprolactam	80			
Suh Tong Chemical	Propylene			150 (8/90)	Yeocheon
	PP			80 (8/90)	
Sangyong Oil Refinery	Benzene			45 (5/90)	
	Toluene			135 (5/90)	
	Xylene			221 (5/90)	

Table B.11. *(continued)*

Company	Item	Existing	Expansion[a]	New Project[a]	Site
			HYOSUNG GROUP (continued)		
Hosung Petrochemical	Cyclohexane	10			
	n-Hexane	10			
Youngwoo Chemical	TMP			5 (12/89)	Hankoo
					TiO 18 30 Onsan
Titanium	TiO	20	8		Inchon
Korea DuPont	POM			10 (89)	Yeocheon
	PVB			? (91)	Yeocheon
Yujin Chemical	POM			15 (89)	
Hankuk Ctsuka	Hydrazine			7.5 (10/90)	Onsan
Hanbul Chemical	Adipic Acid			? (89)	
Dongsung Petrochemical	Butandediol			20 (3/91)	350
	THF			2 (3/91)	Dave McGee
	MA			? (3/91)	(GB)
Koryo Petrochemical	TPA			100	
Kolon Petrochemical	Pet. Resin	10			
	Epoxy				
	Phenol				
Korea Alcohol	Ethanol	30	3 (10/80)		
	CH CHO	24	6 (10/89)		
	Ethyl Acetate				

Table B.11. (*continued*)

Company	Item	Existing	Expansion[a]	New Project[a]	Site
		HYOSUNG GROUP (continued)			
Korea Fine Chemical	TDI	22			
	(HCI 35%)	26			
	Elastomer	5			
Sam Yang	PC			15 (6/90)	Chunju
	PBT				
Samnam Petrochemical	TPA			200 (12/90)	
Oriental Chemical	Adipic Acid			30 (90)	Kunsan
	TDI			25 (12/89)	
Oriental Ato	Hydrazine			6 (5/90)	Kunsan
	Foaming Agent			3 (6/90)	
Namhae Chemical	DNT	15	50 (89)		
	Caprolactam			100	
Ulsan Pacific Chemical	SBR			12 (89)	Ulsan
Sunghwa Petrochemical	MDI			35 (2/89)	

Source: Republic of Korea, Ministry of Science and Technology.

[a] Figures in parentheses indicate the (month and) year that the project came or is expected to come on stream.

Table B.12. Fine chemicals industry—demand and supply prospects
(Hundreds of millions of won)

		1987	1990	1994	2000
Medical	Production	20 111	27 829	40 862	70 380
	Imports	1 443	1 820	3 451	9 094
	Domestic demand	20 774	28 636	42 413	76 032
	Exports	745	1 013	1 899	3 442
Agricultural	Production	2 713	3 660	5 568	8 430
	Imports	1 047	1 247	1 575	2 234
	Domestic demand	3 570	4 489	5 949	8 584
	Exports	190	417	1 193	2 080
Dyestaff	Production	1 495	2 285	3 997	9 245
	Imports	2 176	2 897	4 241	7 513
	Domestic demand	3 372	4 729	7 451	14 958
	Exports	299	453	786	1 800
Paints	Production	4 310	5 879	8 893	16 543
	Imports	407	451	518	637
	Domestic demand	3 987	5 197	7 436	12 635
	Exports	747	1 133	1 975	4 544
Cosmetics	Production	5 290	8 832	13 407	19 018
	Imports	16	56	130	183
	Domestic demand	5 213	8 732	13 273	18 497
	Exports	93	156	355	705
Perfumes	Production	311	542	1 135	3 441
	Imports	477	764	1 431	3 670
	Domestic demand	787	1 303	2 551	6 992
	Exports	1	3	12	73
Catalysts	Production	-	462	716	1 500
	Imports	247	312	581	998
	Domestic demand	247	784	1 297	2 498
	Exports	-	-	-	-
Total	Production	34 230	49 489	74 578	128 557
	Imports	5 813	7 547	11 928	24 347
	Domestic demand	39 950	53 870	80 370	140 178
	Exports	2 075	3 175	6 220	12 644

Table B.12 (*continued*)

Imports as a percentage of consumption	16.0	14.7	15.5	18.1
Exports as a percentage of production	6.3	6.7	8.7	10.5

Source: KIST.

Table B.13. R & D investment of world chemical companies
(Millions of US dollars)

Country	Germany	United States	Switzerland	United Kingdom	Japan (1987)	Republic of Korea (1989)
Amount (1986)	985 (3)	735 (3)	725 (3)	407 (2)	694 (4)	39 (2)

Source: Economic Report, June 1990.

Note: Number of companies shown in parentheses.

Nevertheless, the Institute does not engage in pure advanced materials research for its own sake. Rather, research is only related to industry needs. As is the case with most government-supported organizations, it only supports and assists industry, even though the latter complains that it does not always do so. Here a rise in the participation of foreign companies is noted. In fine, specialty chemicals, KRICT is doing research with companies like DuPont, Monsanto and Hoechst. The reason that such companies conduct joint research programmes around the world with institutions such as KRICT is that, in specialty chemicals, companies require continuous innovation for growth. KRICT has high-level scientific capabilities, and half its manpower is engaged in finding new compounds for chemicals (a new compound can lead to billions of dollars in revenues in pharmaceuticals or agriculture). Even if KRICT were to find a new chemical compound, however, there are enormous costs involved in commercializing and marketing the invention, which from discovery to marketing could take 5-7 years. Hence, KRICT licenses companies to produce a new product; it is currently involved, for example, in licensing chemical companies in Japan.

Given that development costs for a new material can run to $100 million, KRICT is "not capable of wholly participating in the sophisticated process of commercialization", rather, its "main task is to participate with leading research centres around the world in joint research projects for focusing on synthesizing and examining remedial results".[1] If a company is sufficiently capitalized in order to survive the seven years or more it must wait before commercialization of the new product, then the rewards can run into billions of dollars, with profit margins reaching more than 50% of the sales price in pharmaceuticals. In addition to the ability to develop a new technology, the ability to market a new product is of central importance. Hence, knowledge of the stringent approval and distribution regulations, which vary from one national market to another is very important. Despite these difficulties, both pharmaceutical and agricultural chemical companies are steadily moving toward commercialization of new products (e.g., antibiotics) developed in partnership with foreign companies.

KRICT, therefore, is pulled along by domestic demands for materials, by domestic industry and by foreign companies, but collaboration with foreign companies is also seen as preparing a technology science base which can subsequently be used by the domestic companies. It is also recognized that access to foreign science and technology is necessary in order to keep ahead.

The Republic of Korea is, by general admission, at an early stage in advanced materials. Industry is interested but faces large difficulties in these areas. This is especially so in the polymer materials area because of the overproduction trend identified above. Until 1989, there was a great shortage of plastics because of production and exports of major user industries in cars and electronics. Hence, companies did not pay much attention to research, concentrating instead on commodity plastics. Most polymeric advanced materials are blends and composites, which can utilize the overproduction in commodity chemicals. In terms of manpower, there is, in fact, an oversupply of Ph.D. scientists trained abroad, about 8,000 of them from the United States. In KRICT every year around 22-30 (that is, approximately 5%) of the younger staff go abroad to study.

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[1] Chae Yung-Bog, President of KRICT, *Economic Report*, June 1990.

Annex III

PETROCHEMICALS IN TAIWAN PROVINCE OF CHINA

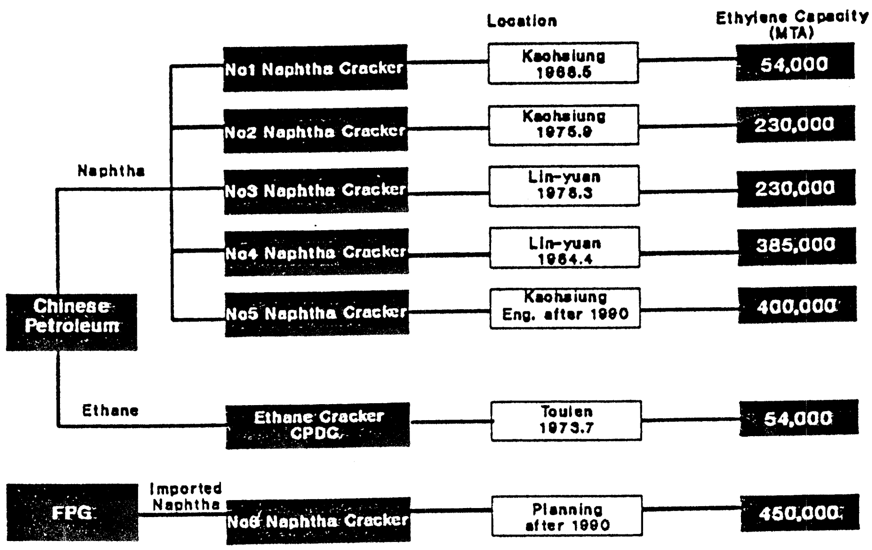
While in the first half of 1989, the petrochemical industry of Taiwan Province of China was at the peak of its business cycle, matters deteriorated rapidly by the third quarter owing to with a slow-down in petrochemical demand. The industry expected a mediocre performance for 1990.

The total value of petrochemical output declined slightly in 1989 from the previous year, due to shortages in raw-material supply, environmental disputes and overseas relocation of some plants further downstream. At the same time, the plans for new plants and expansion of existing ones made little progress, adding to the shortages and bottlenecks faced by the industry. The number 5 and number 6 naphtha cracker projects were delayed for a further year (see figure I), and this was expected to accentuate the shortage of basic petrochemicals and the growing dependence on imports. Current capacity and scheduled expansion plans in all major petrochemicals are given, by company, in table C.1.

The petrochemicals industry is in urgent need of restructuring and technological upgrading in order to maintain its international competitiveness. A number of producers have attempted to meet cost and environment pressures by shifting production to other locations, including overseas.

Growth rates in the demand for major petrochemicals from 1979-1989 are given in figure II. The demand for plastic and synthetic-fibre raw materials is given in figures III and IV. The supply and demand balance in 1990 for major petrochemical raw materials is presented in tables C.2 and C.3.

Figure I. Oil-based petrochemicals
(Upstream plants)



Source: Petrochemicals Industry Association of Taiwan Province of China.

Table C.1. Capacities and expansion plans of major petrochemicals

Product	Producer	Capacity* (thousands of tonnes)	After expansion or debottlenecking Total capacity	Date scheduled
Ethylene	CPDC	54		
	CPC	899	1 015	1992
	FPG	0	450	1992
Propylene	CPC	475.6	574.3	1992
	FPG	0	225	1992
Butadiene	CPC	128	160.5	1992
	FPG	0	75	1992
VCM	FPG	720	1 080	1992
	TVCM	190		
SM	GPPC	200	300	
	TSMC	240		
	FCFC	0	200	1992
CPL	CPDC	100		
	FCFC	0	120	1992
AN	CPDC	132		
PTA	CAPCO	750	1 000	1990
	FCFC	0	200	1990
EO	CMFC	40		
	OUCC	117	224	
EG	CMFC	100		
	OUCC	150	300	
PO	Chiunglong	15		
PG	Chiunglong	9		
MMA	KMC	30		

Table C.1. *(continued)*

Product	Producer	Capacity* (thousands of tonnes)	After expansion or debottlenecking: Total capacity	Date scheduled
Melamine	TFC	10	20	1991
VAM	Diren	100	200	1991
LDPE	USI	140		
	APC	100		
HDPE	USI	80		
	FPC	144	294	1992
LLDPE/HD PE	USI	120		
	FPC	0	140	1992
PVC	FPC	762	830	1990
	CGPC	200		
	Cathy	84		
	Ocean	108		
PP	TPP	200		
	Yung Chia	100	120	1991
PS	Chi Mei	180		
	Taita	40		
	BC Chem	30		
	Kao Fu	60		
	HP	23		
	Dow	12		
	FCFC	0	60	1991
	Others	85		
ABS	Chi Mei	500		
	Taita	50		
	GPPC	40	80	
	Nan Ya	0	50	12/1990
	Others	42	120	1992

Table C.1. (*continued*)

Product	Producer	Capacity* (thousands of tonnes)	After expansion or debottlenecking Total capacity	Date scheduled
SBR	TSRC	100		
BR	TSRC	40		
TPR	TSRC	20		
SBR Latex	President	24		
NBR Rubber	President	10		
HSR	President	3		
PPG	Chiunglong	26		
EVA Emulsion	Diren	40		
PVA	CCP	60		
PVAc	CCP	15		
PVB	CCP	3		
Benzene	CCP	318.5	568.3	1992
	FCFC	0	154	1992
Toluene	CPC	19.5	299.9	1992
Mix-Xylene	CPC	150	499.8	1992
p-Xylene	CPC	200	420	1992
	FCFC	0	180	1992
o-Xylene	CPC	60	120	1992
	FCFC	0	100	1992
Acetaldehyde	LCY	55		
Acetic Acid	CCP	60		
	CPDC	60		
Acetone	LCY	20		
Acetonitrile	Ta Nun	4.5		

Table C.1. *(continued)*

Product	Producer	Capacity* (thousands of tonnes)	After expansion or debottlenecking: Total capacity	After expansion or debottlenecking: Date scheduled
Butyl Acetate	CCP	24		
Diaceton	LCY	2		
Alcohol	LCY	2		
Dimethyl Ether	LCY	3		
DEG	OUCC	11.8	23.6	
DMF	LCY	10		
Ethyl Acetate	Darien	30		
	LCY	40		
Formalin (37%)	LCP	150		
	CCP	108 Formic Acid	LCY	4
Glycol Ether	LCY	15		
Glycol Ether Acetate	LCY	8		
IPA	LCY	50		
Butene-1	TASCO	7		
Nonyl phenol	IUCC	10		
MEK	TASCO	60		
	LCY	20		
Methanol	CCP	66		
	LCY	60		
	CPDC	66		
MIBK	LCY	15		

Table C.1. (*continued*)

Product	Producer	Capacity* (thousands of tonnes)	After expansion or debottlenecking: Total capacity	Date scheduled
MTBE	TASCO	200		
Pentaerythoritol		LCY	13	
Rubber chemicals		Premier	12	
Polymer stabilizer		Premier	12	
Acrylates (Ethyl-)		FPC	75	
	LCY	10		
Acrylamide	CCP	16.5		
Alkyl Benzene	FUCC	90		
Ammonia	TFC	300		
Carbon black	CSRC	58	85	6/1992
Chlorinated Paraffin	Hardy	12		
Choline chloride	LCY	5		
DOP	UPC	140		
	Nan Ya	160		
Dimethyl Suffate	LCY	6		
EDTA	Ta Nan	2.5		
Epoxy resin	CCP	12		
ESBO	CCP	16		
Hexamine	LCY	5		
	CCP	7.2		

Table C.1. *(continued)*

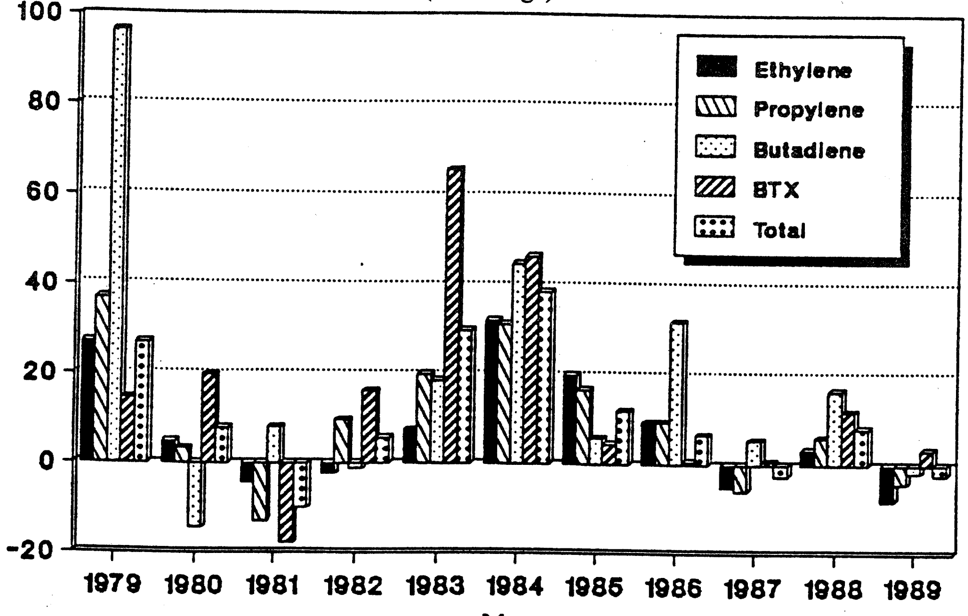
Product	Producer	Capacity* (thousands of tonnes)	After expansion or debottlenecking: Total capacity	Date scheduled
Hydrogen peroxide	CCP	20		
MA	UPC	3	0	2/1991
	GUCC	0	20	1990
	Nan Ya	0	20	1992
	TASCO	0	15	1990
Methylamines	LCY	10		
Paraformaldehyde		CCP	10	
	LCY	6		
PA	UPC	60	90	10/1991
n-Paraffin	HTCC	40		
Solid NaCN (97%)		Ta Nun	12	
Liq. NaCN (33%)		Ta Nun	20	
TMP	CCP	3		
	LCY	5		
Urea	TFC	286		

Source: Petrochemicals Industry Association of Taiwan Province of China.

* As of April 1990.

Figure II. Demand analysis of major petrochemicals: Growth rate in basic feedstock demand

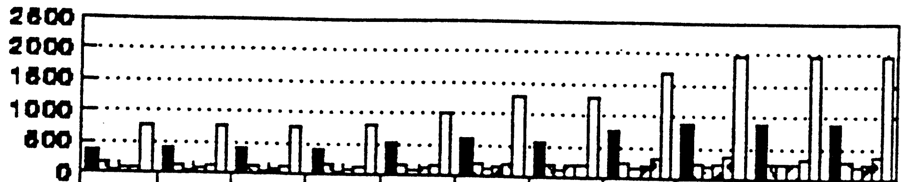
(Percentage)



Source: Petrochemicals Industry Association of the Taiwan Province of China.

Figure III. Demand analysis of major petrochemicals

Total demand for major plastics



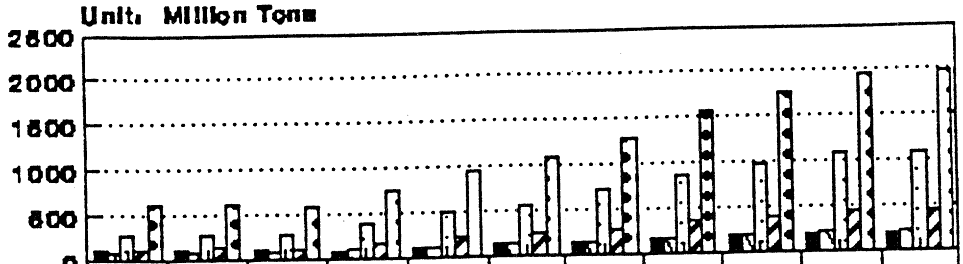
	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
PVC	379	410	422	417	507	620	678	762	892	890	883
LDPE	160	127	122	141	172	192	209	267	266	247	263
HDPE	49	63	51	47	71	106	130	176	211	239	212
PP	79	91	86	74	127	165	156	207	230	266	267
PS/ABS	93	101	111	120	163	192	206	311	379	338	371
Total	760	782	771	799	1000	1270	1307	1701	1966	1969	1966

Year

PVC; LDPE; HDPE; PP; PS/ABS; Total

Source: Petrochemicals Industry Association of the Taiwan Province of China.

Figure IV. Demand analysis of major petrochemicals:
Demand for synthetic-fibre raw materials



	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
CPL	103	113	113	92	109	135	141	167	196	209	199
AN	96	75	94	109	121	147	148	163	202	222	219
PTA	286	286	286	383	612	667	722	866	977	1031	1102
EG	123	132	106	164	212	246	277	370	387	464	469
Total	610	609	599	747	964	1099	1289	1666	1769	1966	1979

Year

CPL AN PTA EG Total

Source: Petrochemicals Industry Association of Taiwan Province of China.

Table C.2. Supply and demand of petrochemical raw materials, 1990
(Tons)

Plants	Sources of raw materials		
	Ethylene	Propylene	Butadiene
Cracker 1	54 000	27 000	-
Cracker 2	230 000	104 300	35 000
Cracker 3	230 000	104 300	35 000
Cracker 4	385 000	200 000	58 000
Ethane cracker	54 000	-	-
CC	-	40 000	-
Total	953 000	475 600	128 000

Table C.2. (*continued*)
Sources of raw materials

Plants	Benzene	Toluene	Xylene
Aromatics 2	37 000	48 500	57 000
Aromatics 3	36 500	116 000	190 000
Aromatics 4	159 000	101 500	93 000
Others	139 000	6 000	132 500
Total	371 500	272 000	472 500
In-plant conv. (minus)	53 000	252 500	322 500
Act yield	318 500	19 500	150 000

Source: Petrochemicals Industry Association of Taiwan Province of China.

Table C.3. Outlets: petrochemical raw materials

Ethylene		Propylene		Butadiene			
FPC	288 400	CPDC	155 000	TSRC	101 000		
USIFE	199 500	TPP	128 800	President	5 500		
OUCC	93 000	Yung Chia	88 000	Others	21 200		
APC	100 000	LCY	25 000				
CMFC	70 000	FPC	18 000				
Grand Pacific	62 000	Chiunglong	13 800				
TVCM	55 000						
Darien	35 000						
TSMC	29 500						
LCY	25 000						
TPP	1 500						
Yung Chia	3 800						
Total	962 700	Total	428 600	Total	127 700		
Benzene		**Toluene**		**Xylene**		**Bottom oil**	
CPDC	51 000	CPDC	960	CAPCO (PX)	200 000	CSRC	120 000
Grand Pacific	84 000			UPC(OX)	60 000		
FUCC	15 000						
TSMC	60 000						
TSRC	1 200						
Total	211 200	Total	960	Total	260 000	Total	120 000

Source: Petrochemicals Industry Association of Taiwan Province of China.

REFERENCES

1. Materials Science and Engineering in the 1990s: Maintaining Competitiveness in the Age of Materials, Committee on Materials Science and Engineering, National Academy Press (Washington, D.C., 1989).

2. United States National Research Council, *Materials Science and Engineering for the 1990s*, National Academy Press, Washington, D.C., 1989.

3. United States Bureau of Mines, *The New Materials Society*, vol. 2, 1990, chapters 4 and 5.

4. Melvin Kransberg and Cyril Stanley Smith, "Materials in History and Society", in *The Materials Revolution*, Tom Forestor (ed), Basil Blackwell, 1988.

5. "The Restructuring of Industry 1970s-1990s", by L. Kaounides, a paper presented at the fourth EADI Conference, Oslo, June 1990, upon which this section is based.

6. Strategic Materials: Technologies to Reduce United States Import Vulnerability, United States Congress, Office of Technology Assessment (OTA), May 1985, and Potential of Ceramic Materials to Replace Cobalt, Chromium, Manganese, and Platinum in Critical Applications, MIT study for OTA, January 1984.

7. E.D. Hondros, Director, EC Research Centre, Petten, in *The Materials Revolution*, Tom Forester (ed.), Basil Blackwell, 1988.

8. Working Papers of the MIT Commission on Industrial Productivity, vol. 1, MIT Press, 1989.

9. *Far Eastern Economic Review*, January 1992.

10. R. Schonberger, Japanese Manufacturing Techniques, Free Press, and R. Schonberger, World Class Manufacturing. T. Kaupe and P.T. Bolwijn, "Manufacturing: The New Case for Vertical Integration", *Harvard Business Review*, March-April 1988.

11. "The Coming of the Japanese Keiretsu", *Harvard Business Review*.

12. "Keiretsu", *Tokyo Business Today*, September 1990.

13. "Report of the National Critical Technologies Panel", Washington, D.C., March 1991.

14. Horst Czichos, R. Helms and J. Lexow, *Industrial and Materials Technologies: Research and Development Trends and Needs*, BAM, Berlin, 1991, Forschungsbericht 181.

15. L. Kaounides, "Advanced Materials and Industrial Restructuring in Japan and South-East Asia 1980s-1990s", a paper presented at the Expert Group Meeting on Materials Policy Issues, Bangalore, India, December 1991.

16. L. Kaounides, Final Report, EGM, Materials Policy Issues, Bangalore, India, UNIDO, July 1992.

17. L. Kaounides, "Advanced Materials in World Class Manufacturing: The next source of competitive advantage", a paper to be presented at the British Academy of Management Conference, Management into the 21st Century, September 1992.

18. "The Science and Technology Resources of Japan: A Comparison with the United States", United States National Science Foundation, NSF 1988-318.

19. Lakis Kaounides, "The Materials Revolution and Economic Development", Institute of Development Studies, Bulletin, vol. 21, April 1990; L. Kaounides.

20. "New Advanced and Improved Materials and Processes: The revolution in materials science and engineering and its strategic implications for developing economies in the 1990s", UNIDO, December 1990.

21. "Advanced Materials and Primary Commodities", paper presented at Expert Group Meeting on Prospects for Industrialization Policies in Developing Countries, UNIDO, Vienna, Austria 4-7 April 1990. A condensed version of the latter appears in New Technologies and Global Industrialization, UNIDO, PPD 141, November 1989.

22. Expert Group Meeting on Materials Policy Issues, Final Report, UNIDO National Materials Policy Project, TIFAC/Dept. of Science and Technology, Bangalore, India, 11-13 December 1991, UNIDO, July 1992.

23. Advanced Materials Technologies--Strategies for Growth, L.C. Kaounides and R.S. Ganapathy (eds.), UNIDO/Institute of Materials, London, Spring 1993 (forthcoming).

24. *The Materials Revolution and Economic Development*, EADI/Frank Cass, L.C. Kaounides and M. Muchie (eds.), London, Spring 1993 (forthcoming).

25. "Current Revolution in New Materials: Opportunities for the Developing World", by Professor Pradeep Rohatgi presented at the Regional Workshop on Advanced Materials Technology and Development in Asia and the Pacific, Minsk, USSR, 29 May - 2 June 1989.

26. "Neodymium Supermagnet—Key Material for Tomorrow's Electrical and Electronic Industry", by N.C. Kothari and presented at the Regional Workshop on Advanced Materials Technology and Development in Asia and the Pacific, Minsk, USSR, 29 May - 2 June 1989.

27. P. Cohendet *et al.*, *New Advanced Materials* (Springer-Verlag, 1988).

28. *Japan Chemical Week*, 9 November 1989.

29. Chae Yung-Bog, President of KRICT, *Economic Report*, June 1990.

Discussion of Part One, Paper Two

Mr. Ghazi Derwish:

Q. Regarding the role of Governments versus market forces in the area, as you know, our area is highly underdeveloped with regard to science and technology. There is therefore no escape from the direct and very active intervention by Governments, especially, to build up relevant capabilities in both science and technology. I therefore think that, with regard to materials, the role of Government is crucial. What has gone wrong in the past was that Governments tried to overrule market forces. This is where they went wrong. Governments, in my view, could do better if they paid greater attention to market forces.

With regard to the interest shown by the Arab universities in the science and technology of materials and also in related subjects, including metallurgy, it is curious to see that in many Arab universities there is an absence of departments concerned particularly with materials science and engineering and with metallurgy. Only recently have some of these universities taken measures to remedy this situation.

Mr. Suham Al-Madfai:

Q. In the marketing of advanced materials, can you give us any opinion as to whether international barriers exist regarding the movement of such materials between countries or economic blocs, as is the case in petrochemicals? This is a serious problem for the Arab countries.

Q. The field of materials technology is dynamic and highly competitive; it would need continuous scientific backing for basic science and R&D. Can you give us an idea about the magnitude of capital or cost spent on R&D in this industry?

Mr. Nabil Ghoneim:

Q. My question concerns the natural resources in the developed countries. We all know that the advanced materials products are not necessarily prepared or synthesized from natural resources. They are mostly from available materials, chemicals and so on. This represents a problem for the Arab countries, which have an abundance of natural resources. They have to start extracting the raw materials for the advanced products from these natural resources, if possible, or they have to buy them from developed countries. In both cases, it represents some sort of burden to the ailing economies of some ESCWA member countries. How do you find the impact on the economy of these countries in this respect, particularly if they have to face the dual task of extracting or producing the starting materials and manufacturing the products at the same time?

Mr. R.S. Ganapathy:

Q. The issues and principles you raised such as modern materials, major industries, the need for sciences and long-term strategies, the need to integrate industrial policies and science and technology policies, and the need for more material cycle perspective, i.e. to look from design to disposal, are not exceptional and are accepted. However, I want to raise one or two questions over the conclusions with relevance to the region.

First, it seems that strategies in the area of materials will have to be heavily context-dependent. They will have to consider the social context, the size of the country, its resource base, institutional structure, traditional educational capabilities for innovation that exist. I am saying that the initial conditions that prevail in the region would, to a large extent, determine the success, of a particular strategy. The institutional structures cannot be transplanted regardless of experience, whether PIST or MITI were successful in some context does not mean they will be successful here, and we in India and many other countries have a great deal of experience to state that. So I wanted to make this point clear, that we cannot transplant an institutional structure or a particular strategy. They have to be context-dependent.

The second point which you mentioned is the role of Government and industry and market forces. I think a colleague remarked on this point, but what I want to emphasize is that unless we redefine very clearly what Government or industry can do, we cannot draw lessons. Again, the nature of industries is quite different here and depends on the market forces we facilitate.

The third point, which I think you may have implied in your presentation, is the role of traditional materials. The region is quite rich in traditional materials. How can we use our knowledge in using technology to improve the quality, efficiency and competitiveness of those traditional materials?

Advanced materials are very glamorous; look at fine ceramics and metal matrix composites. However, demand is likely to be very small. Moreover, the cost of technology development is prohibitively high. So I think the concern should be on the role of traditional materials, which is where the region's comparative advantage is; where it can position itself through value-added traditional materials in the global market; export raw materials and commodities, if not agricultural raw materials.

Mr. Lakis Kaounides:

Ans. I would like to point out that all the points raised are actually discussed in my paper. I just had to rush through it. There are 20 pages on the role of traditional materials.

First of all, I believe that one of the most important issues about materials science and engineering development now in the developing world is using local resources to meet basic needs and perhaps also slowly moving to increase the competitiveness of export industries directly or through the export of the materials themselves. As yet, we have not really done any serious study. I think India could produce an enormous amount of information, and I am very impressed by the work in India. India can give a lead in many areas because it has a very strong science base, if only the professionals spoke to some Indian professors there. There are two problems. One, Indian scientists are not interested in addressing basic needs, it is not glamorous for them, and this is a very important point. Secondly, those who do, cannot find any acceptance. Anybody who wants to actually utilize these materials could do so; the market has potential. A professor was telling me that he had developed a new filter for water purification; nobody was interested in developing it. The market is vast if it is developed. The potential is enormous; we have a strong knowledge base to address development issues very powerfully. India has intellectual resources and has already done many studies. I think it will be very interesting if you can produce some studies on how you can utilize local materials. I have seen two studies by Mr. Rohatgi, and I have included a page from his paper in mine because I consider it very important indeed. He addresses the issue of materials in the developing countries and how we can use advanced materials to meet local needs. Moreover, I have just received a fax from the United Nations on another paper by Mr. Rohatgi which is on advanced composites utilizing domestic materials, a very important study. I think these are the kind of things we should be looking at in this workshop.

Secondly, I never said that we should transplant the institutions of Japan or the Republic of Korea or whatever. They are only interesting ideas. They address materials issues in relation to industry, and they are starting to link them. That is all I have said.

Now, how does this fit in with Arab institutions? I think this is another issue and a very difficult one. I cannot express an opinion because I do not know the local conditions very well. All I can say is that I have seen these things and they are very interesting and perhaps we should discuss them here. Hence, definitely the social context of the Republic of Korea and Taiwan Province of China, etc., is completely different, and that is a very important point which Mr. Ganapathy has made. These things depend on the stage of development of industry and institutions, and I have made this point in the paper. I will link the points here, although I am not quite sure I am going to answer you. In terms of utilizing domestic resources and moving up the high value-added ladder it is quite difficult, but it can be done. For example, traditional metallurgical strength can easily be converted into ceramics, what Japan and other countries have abandoned. You can utilize the experience of the Republic of Korea. How did it develop the ceramics industry? Ten or fifteen years ago, the Republic of Korea did not have an advanced ceramics industry; it had pottery and clay. How did they do it? Their universities developed the programmes. They have many Ph.D.s and ceramics specialists. In national conferences, papers from the Republic of Korea are coming out. You put your resources in education, gear your educational systems towards that end and you begin to develop the infrastructure, which might enable you to take the traditional ceramics industry and move up.

This brings us back to the issue of the role of Government versus the market. They have to be industry-driven, user-driven, which I did not mention but, again, it is in the paper. The Government is there to provide the framework and assistance. I have a long list of what the Government can do, but all of it must be industry oriented.

Paper Three

TESTING AND EVALUATION OF ADVANCED MATERIALS

M. Kamal Hossain
National Physical Laboratory

In recent years, innovations in materials technology have provided significant opportunities for new and improved products in diverse industrial sectors, with considerable economic and competitive advantages, and the pace is set to continue. Reliable methods of materials testing and evaluation are widely recognized to be crucial for the successful development of advanced materials and, more importantly, for their incorporation into products. Appropriate evaluation techniques and good quality data on properties are needed for materials selection, product design, process selection, quality control and assurance, and the prediction of in-service performance. In fact, the absence of sufficiently robust evaluation methods acts as a barrier to the diffusion of the technology.

Increasing complexities in modern materials, advances in manufacturing technology, and the use of materials near the limits of their performance in demanding conditions require a more rigorous approach to materials testing and analysis than what has been done hitherto. Technical bases from which widely acceptable test methods and standards can be generated are in demand but require much effort and resources. There is thus a strong case for international cooperation in this field. Such cooperation should help to stimulate international trade in new materials and their products.

In this paper a review of the key issues in materials testing, evaluation and standards will be discussed with reference to engineering ceramics, advanced metallic materials, polymers and composites. The responses and experiences of the developed countries will be discussed, including future trends and directions. Various current forms of international cooperation in test methods and standards development are presented. Also, a brief analysis of appropriate responses to these trends by Middle Eastern economies, mainly those dependent on the export of raw materials, is provided.

Introduction

From the early days of mankind, the ability to fashion and use materials has played a central role in the development and growth of society, affecting its prosperity and the quality of life. This is true, perhaps more so now, because of the rapid advances made in materials science and technology in recent years. Effective use of materials is vital to economic growth and industrial competitiveness as well as health, environment and safety. Since rapid developments in advanced materials and processing offer unprecedented opportunities for growth in new and improved products, materials technology is being targeted by industry and Governments around the world as priorities for investment. While industrial investments are aimed at product development and increasing efficiency, Governments have tended to focus on supporting underpinning activities such as strategic and pre-competitive research, technology transfer, demonstrator projects and frameworks for measurement and evaluation.

Modern engineering materials can be divided into two primary categories: functional and structural. Functional materials have certain intrinsic properties which are used in devices such as electronics chips and sensors; structural materials, on the other hand, have extrinsic properties which enable them to perform structural or mechanical functions such as transmitting force and bearing loads. The variety of advanced materials ranges from existing modern materials which are being improved to extend their performance and applications, to those that are being developed with unique and unprecedented properties. Some examples of technological advances based on materials development are the following:

(a) In integrated circuits, the number of components per chip has increased from about 10 in the 1960s to 10^6 currently due to improvements in materials and processing technologies;

(b) New magnetic materials based on rare earth/cobalt alloys and recently iron/boron compounds have led to permanent magnets with magnetic strengths some 100 times greater than steel. Smaller and more powerful motors can be made using these materials to improve the functionality of many machines and devices used every day;

(c) Improvements in tool materials have increased cutting speeds by up to 100% and at the same time increased the life of tools by an order of magnitude;

(d) In civil engineering as well, modern economic designs have been made possible only by the progressive improvements in materials. For example, a comparison of modern thin-deck suspension bridges which carry highways across estuaries, with the massive cantilever railway bridges of the last century indicates the importance of such developments to modern communications and transport.

It is important to appreciate in this context that the greatest benefits of new materials are derived from their conversion into products. In this paper, we discuss the role of testing and evaluation in the application of materials technology, largely with reference to structural materials. However, the basic and more general points made here are equally valid for functional materials.

Importance of testing and evaluation

The significant advantages of advanced materials stem from their performance and processing characteristics. Market requirements tend to dictate their use in more demanding applications, in areas of greater added value, and in products emphasizing greater design efficiency than traditional materials. All of these require reliable information on materials characteristics and data on properties obtained using sound materials evaluation techniques. Methods of measurement, testing or analysis are needed to determine the physical, mechanical or chemical properties of materials.

The benefits of reliable testing and evaluation methodologies are widespread and can be identified for the following purposes:

Quality control and assurance
Materials specifications
Engineering design
Product development
Performance assessment
Materials development.

Let us consider the use of materials in the industrial production cycle as shown in figure 1.

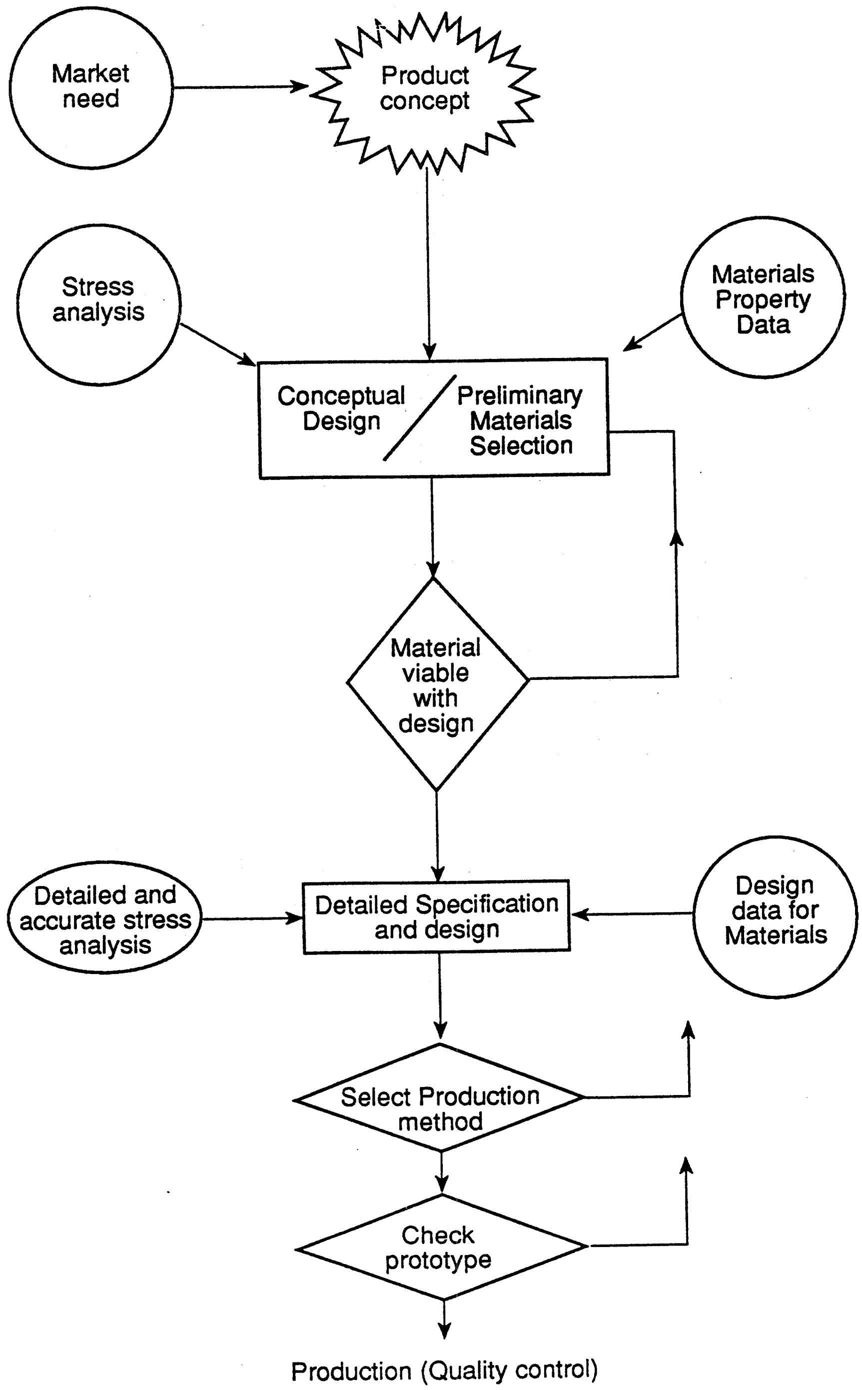


Figure 1. USE OF ADVANCED MATERIAL BY MANUFACTURING INDUSTRY

Based on an identified market need, the designer develops preliminary ideas for a product and makes an initial material selection. To do this, the required function of the product, such as the ability to withstand load, within certain limitations on deflection, is examined in the light of stress analysis (bending, fatigues, contact stresses, etc.). Data needed for the preliminary selection of materials are relatively straightforward, and often a family of materials is chosen at this stage. Detailed design of the product using more accurate stress analysis (finite element, etc.) is then undertaken in conjunction with design data for materials. The production method is also considered carefully at this stage, bearing in mind the need to meet the cost and quality targets of the end product. Prototypes are then made and tested before going into final production. Thus, testing and evaluation data must be available at each stage, but the type and stringency of testing varies according to whether one is dealing with materials selection, design or production.

It may be useful here to touch briefly on non-destructive evaluation (NDE). NDE techniques are often used by industry for flaw detection and defect screening in materials and structures as a means of improving product reliability. Increasingly, NDE is in demand for raw-material characterization, in-process control and life-cycle monitoring. A key goal is to develop NDE techniques amenable to automation and computerization for feedback control. These can be used to measure specific properties on-line in intelligent processing systems. New sensor technologies are being developed to meet this aim.

Properties data are generated principally by materials suppliers, but large materials users also generate their own to increase confidence in and the competitiveness of their products. Data are provided in data sheets and, increasingly, in computer databases, sometimes coupled with computer software for materials selection or product/process design. There are two key problems in this context: (a) lack of credibility of data for design purposes and (b) lack of comparability of data from different sources.

With regard to the first point, it is generally recognized that data requirements for design purposes are more demanding than those for materials selection, specification and quality control. Thus, data for design purposes should be concise, accurate and, importantly, appropriate to the design procedure. The factors that affect the credibility of design data are sundry: lack of precision; data obtained under inapplicable conditions or conditions not fully defined; quantitative relationships of characteristic parameters necessary for interpolation and extrapolation; and unavailability of adequate design procedures with known limits of application.

Incomparability of data from different sources arises from a lack of harmonized or standardized test methods. This is an important issue and is discussed later.

Problems in advanced materials evaluation

Advanced materials often require a new approach or more sophisticated and systematized techniques for evaluation which are not widely available. Problems can arise because:

(a) The structure and behaviour of advanced materials can be very complex and difficult to understand;

(b) Different or new criteria for failure may be required;

(c) These materials are used in more demanding or extreme conditions which are difficult to test for;

(d) Growth in computer-aided engineering techniques, both to optimize processing and to improve design, often demand a new range of data and data of much higher accuracy than before;

(e) Existing test and evaluation techniques have to be applied near their limits in many cases;

(f) There is a lack of suitable design methodologies which define measurement needs;

(g) Reference materials are not available, making it difficult to calibrate measuring instruments with confidence.

Some of the points can be illustrated by the following examples:

High-temperature ceramics. Advanced ceramic materials available now with remarkable optical, electrical, thermal, chemical and mechanical properties are increasingly finding new engineering applications. So far, functional ceramics utilizing electromagnetic properties have been most successful in the market, but there is a considerable growth potential in structural applications such as gas turbines, where ceramic components will allow increased operating temperatures to improve fuel efficiency. The material requirements are the ability to withstand stress at temperatures as high as 1500-1600°C in hostile environments for extended periods of time while maintaining a tolerance of existing or newly created defects. The high stiffness and resistance to damage of ceramics, coupled with the requirement for testing at very high temperatures, poses particular problems in the development of test methods for these materials (1).[1]

Immediately one encounters problems associated with measurements of (a) uniaxial properties without introducing secondary bending stresses and (b) small strains accurately at high temperatures. Even the maintenance of a uniform temperature and the measurement of the test-piece temperature can be a serious problem.

Increasingly, finer raw materials are being used to make advanced ceramic products in order to improve properties and reliability. As a result, measurement requirements are shifting from micron- to manometer-size powders, bringing new challenges to characterization techniques and process control. In finished products using advanced ceramics, flaws as small as one micron at the surface can cause the part to fail during use. Hence, reliable defect-detection techniques are required for quality-control purposes during processing.

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[1] For the list of references, see page 281.

Metal-matrix composites (MMCs). In recent years, the advent of quality ceramic fibres and particulate reinforcements has led to new developments in metal-matrix composites using light metals such as Al, Ti or Mg as the matrix, the primary advantage coming from enhanced strength or stiffness, both at room and elevated temperatures. Additional improvements in fatigue and wear resistance have been achieved, and properties such as thermal expansion can be tailored to meet specific application needs. Developments in MMCs have been led by the requirements of the aerospace and defence industries, but there is increasing interest in the automotive sector (piston crowns, connecting rods, etc.) and also the leisure industries.

Use of MMCs in high-performance components and products requires data of high pedigree. However, the determination of even a basic property such as modulus cannot be achieved with confidence at present. A recent round-robin carried out by the National Physical Laboratory (NPL) (2) on the measurement of Young's modulus for a silicon carbide particulate-reinforced aluminium alloy shows a 20-25% scatter, which is highly unsatisfactory for design purposes. Careful analysis of the results has shown that methods based on testing of traditional metallic materials can be applied, but a rigorous approach in specimen alignment and strain measurement must be adopted. Furthermore, the linear portion of the stress-strain curve is relatively short for MMCs compared with conventional metallic materials, and, therefore, particular car has to be taken in analysing the data.

Fracture toughness (the tolerance of a material to the existence of cracks arising from manufacture or service) is a very important engineering parameter. In calculations of structural integrity, the plane strain fracture toughness (KI_c) is used by engineers and designers to determine the relationship between defect size and applied stress. With MMC testing (3), there is a real problem in obtaining valid data from tests using standard procedures for metallic materials (e.g. British Standard 5447 or ASTM Standard E399). This is because excessive crack curvature occurs in specimens. The problem of crack curvature is severe in MMCs, particularly with high-volume fraction of reinforcements and high-strength matrix alloys. Furthermore, the problem becomes more pronounced as the specimen thickness increases. A proper understanding of the effects of residual stresses on crack curvature is needed before a reliable fracture toughness test method can be devised.

Polymer-matrix composites. Fibre-reinforced composites, owing to their combination of properties (high stiffness, strength-to-weight ratios, damage tolerance and resistance to chemical attack) find engineering applications in many demanding situations. One of the biggest advantages of these materials is that they can be designed for highly specific purposes with their own integral macrostructure determined by characteristics such as fibre orientation and distribution, volume fraction of reinforcing phase, matrix characteristics and fibre length. This flexibility, however, makes it costly to design and test structures or components. Materials data supplied by the manufacturer are produced under very restricted conditions of, *inter alia*, orientation, geometry, temperature, fatigue and environmental exposure. Properties of the finished product may vary considerably from the material in its raw state, and therefore the manufacturer or products has to undertake a substantial amount of testing. This is extremely costly: $50,000.00-$75,000.00 for material for basic tests and as much as $1.0 to 1.5 million for full qualification (4).

From a technical point of view, matrix damage, debonding of fibres, fibre breaks, and delamination between layers are all difficult to establish. Another area of difficulty is in the measurement of strain—many composites used in aerospace applications, for example, have low strain characteristics coupled with anisotropy, and this places severe demands on the capability of extensometry used in strain measurement. Strain-gauges can be used, but they make the testing very time-consuming and expensive.

Standards for test methods

The testing needs of advanced materials are dominated by user requirements. For simple pragmatic reasons and expediency, each user tries to develop its own set of test methods to characterize and qualify a material and to establish allowable designs. Thus, although the need for basic materials properties data is essentially the same for many users, methods used to determine those properties are different. For example, numerous test methods are used worldwide (5) to assess the flexural behaviour of advanced ceramics. Multiple test methods undoubtedly lead to ambiguities and inefficiencies with consequent penalties for materials users, suppliers and test houses alike. Key disadvantages are:

(a) Duplication of testing work for materials suppliers and users;

(b) Different test facilities are costly to establish and operate;

(c) Training to develop expertise for each method can expensive;

(d) Test results cannot be used or put into a database for wider benefit.

In fact, what industry needs is a set of consistent and widely recognized evaluation techniques for common use by both the producers and users of new and advanced materials. Ideally, these techniques should be standardized, but the technical base from which reliable standards for key materials properties can be developed is lacking in many areas. Not surprisingly, experts disagree among themselves on the validity of evaluation techniques and sometimes even on the interpretation of results obtained from the same technique. It is widely acknowledged that, in many areas of advanced materials, research is needed before suitable standardized methods with appropriate accuracy can be developed for industrial measurement needs.

Testing and evaluation activities in different countries

We should now briefly consider the position in different countries in the materials testing and evaluation work. Frameworks for such activities are different in different countries, and it is clear that many organizations are involved with significant capabilities and that there is scope for greater coordination and cooperation.

The United Kingdom. Work on evaluation and testing of advanced materials is carried out in the United Kingdom by industry, universities and government agencies. Industry is generally most active in near-market work which directly benefits its own products and processes. Thus, testing of specific materials in specific conditions takes priority since it meets the needs of quality control, specifications or qualification of particular products; however, much of the information remains confidential on commercial grounds. Industry also plays a part in national and international standardization programmes.

Universities, on the other hand, concentrate on the underpinnings of the scientific aspects of materials behaviour and performance from which new materials, as well as developments of characterization and measurement techniques, emerge. Increasingly, universities are working with industry in collaborative projects through Government-sponsored schemes and direct contracts, but their primary interest is in developing the science and engineering base for materials technology as a whole.

The Department of Trade and Industry (DTI) has the primary role in the provision of a widely recognized framework for materials evaluation and testing which benefits industry in the United Kingdom as a whole. Despite the competitive advantages of adopting a new material or process, it is widely acknowledged that industry faces a significant risk. To assess this risk, designers and product engineers must be able to establish whether a new product, made from different materials or by a different process, will perform in service better than an existing product. Consequently, designers will only use a new material if its behaviour is understood well enough and can be measured by the use of a validated and widely recognized framework. To increase the diffusion of advanced materials, DTI supports test and measurement work on advanced materials. The main objectives are:

(a) To give designers and production engineers sufficient confidence that the performance they require will be delivered by particular materials and processes;

(b) To reduce lead time between innovation and application of advanced materials by industry;

(c) To strengthen the position of the United Kingdom in negotiations on European and international standards and enhance the benefits of standardization in the Single Market;

(d) To strengthen the research and development base of the United Kingdom;

(e) To meet the market's need for an objective authority supplying reliable reference data and guidance on measurement methods.

This underpinning research covers a number of sectors: polymers and composites, high-temperature materials, ceramics and cermets, process modelling and measurements, thermochemistry, surface chemical analysis, and degradation of materials due to environmental attack. The outcome of the work will include:

(a) New and improved methods of testing for wide use by industry;

(b) A mathematical model for predicting materials behaviour;

(c) Data banks on the characteristics and performance of engineering materials;

(d) Design guides/methodologies and best-practice procedures for the use of materials;

(e) Codes of practice for the manufacture and processing of materials.

The focus for the DTI-supported test and measurement work on advanced materials is at NPL. Other research agencies and organizations in the private and public sectors undertake part of the work in niche areas; however, the widespread expertise and standing of NPL, nationally and internationally, mean that the Laboratory is in a good position to act as the leader in the provision of a national infrastructure for materials evaluation. Its independent position allows industry to interact in a free and effective manner.

Laboratory accreditation. In the United Kingdom, a laboratory accreditation scheme is operated under the National Measurement Accreditation Service (NAMAS), which currently has over 1,100 approved laboratories. A number of these are accredited for materials testing work. Accreditation provides confidence in the overall quality of operation of a laboratory with regard to its staff, facilities, equipment, calibration, test methods and procedures, recording of results and production of reports. It does not guarantee that individual test results or data are correct or valid; it merely judges the competence of a laboratory.

From a user's point of view, the same test carried out in different accredited laboratories, even across national boundaries, to a standard specification should produce similar results. Clearly, to achieve this, standardized test and measurement methods are vital, but often there is also a need for certified reference materials for comparisons between laboratories and for proficiency checks.

Europe as a whole. Many of the other countries in Europe also have a good network of laboratories active in materials evaluation and testing. This includes government, industry and academic establishments. Again, government laboratories usually cater primarily to underpinning, strategic and infrastructural elements. Among the key players are BAM in Germany, LNE in France, ENEA in Italy and the Joint Research Centres of the Community based at Petten (Netherlands) and Ispra (Italy).

The Commission of the European Communities (CEC) supports industrial and materials technologies through various programmes, the largest being BRITE/EURAM (633 million ECU, 1990-1994). Work on industrial materials is aimed at improving the performance of materials at a cost which allows competitive industrial exploitation over a broad range of applications. Measurement and testing work is not specifically addressed but is included in projects as a necessary element of the overall R&D work.

The CEC operates a Measurement and Testing Programme managed by the BCR (Bureau Communautaire de Référence). The latest programme (140 million ECU over four years) is aimed at improving measurements, testing techniques and chemical analysis in areas where there are problems in mutual agreement or measurement methods are insufficient to satisfy the new challenges in industry, in monitoring of the environment, food, quality and health. A proportion of the support will be devoted to materials testing.

Emphasis is placed on tasks which provide solutions to difficult measurements required for (a) the implementation of Community regulations and directives, (b) standards (norms) on industrial products; (c) for new and advanced technologies, and (d) for resolving urgent problems of trade. Support is given:

(a) To establish the basic know-how;

(b) To provide a basis for developing guidelines to avoid recurring mistakes, which is important both for laboratory practice and for laboratory accreditation; and

(c) To establish means of calibration and verification of the measurement procedures which should be available to all laboratories concerned in the member States.

The United States and Japan. Both countries have extensive programmes on materials R&D, and testing forms an integral part. In the United States, for example, the Federal Government recently announced the "Advanced Materials and Processing Programme (AMPP)", which is a coordinated integral effort of government agencies to exploit opportunities in materials R&D to meet national goals. Materials characterization encompassing structure, composition, properties and performance forms one of the four key elements of the programme. In 1992 expenditure on activities in this category is budgeted at about $473 million and is due to increase by $30 million next year. In underpinning work on developments of validated and traceable measurement methods, the National Institute of Science and Technology (NIST) plays a key part. Similarly, in Japan, the National Research Institute on Metals (NRIM), the National Research Institute on Inorganic Materials (NRIIM) and Polymer and Textile Laboratories deserve special mention.

The Republic of Korea. Now it would be interesting to consider briefly the situation in the Republic of Korea, a country which has made rapid transitions from a labour-intensive economy to high-technology and higher value added products such as computers and microelectronics. Advanced materials play a crucial role in this movement, but the country imports a large proportion of these materials from Japan and the United States. To reduce this dependency, the Government of the Republic of Korea, through its Ministry of Science and Technology (MOST), has adopted a Materials Technology Development Plan with substantial investments in R&D ($330 million over five years [1991-1996]).

The Government has also carried out a national survey in which materials evaluation technology was identified as an area requiring priority action. In recognition of the fact that industry is reluctant to fund underpinning work towards the development of test and evaluation methods, MOST has established a Materials Evaluation Centre (MEC) at the Korean Research Institute for Standards and Science (KRISS). It has a central role supporting national objectives associated with industrial development and exploration of advanced materials.

Less industrialized countries. Earlier this year, UNIDO carried out a consultation exercise with leading experts and institutions in nine countries in Asia and America about advanced materials testing and evaluation work and future needs. Generally, the effort and resources are dispersed in the developing countries and it was commonly acknowledged that improved coordination and cooperation across national boundaries would be highly beneficial. In addition to improvements in the technological capabilities of individual countries, there would be considerable synergistic benefits from cooperative work. Therefore, UNIDO is exploring mechanisms for establishing a suitable framework and an international centre for materials evaluation technology for developing countries.

Developments in international standards

International. In the field of standardization, enormous changes are taking place and there is now common recognition throughout the world that emphasis should be placed, wherever possible, on worldwide rather than national or international standardization. At present, there are very few truly international standards on advanced materials. So far, international standardization has been relatively slow because standards have been developed after the market entry of new products, which has traditionally required elaborate consensus procedures involving representation by all interests concerned. The aim has been to ensure fair competition and protection of market interests. Naturally, much of the effort of the two international standards bodies—ISO and IEC—has concentrated on harmonization of differing national standards.

By contrast, a stimulating analysis of the potential contribution of standardization in the process of technological innovation has been made in the ISO/IEC publication entitled *A Vision for the Future* (6), which comprises a study of technological trends and the results of a worldwide survey by a team of top industrialists and businessmen of standardization needs for emerging and rapidly developing technologies such as IT, biotechnology and materials. The report highlights modern industrial economy characterized increasingly by production systems dispersed transnationally, and the shift of key elements of production control from design specification of mechanical parts and machines to performance requirements for processes and interfaces.

In the context of a fast-developing technology such as materials, different aspects of standardization can be related to separate stages of innovation and product development cycles, from the early stages of innovation through the market entry and product development. In the early phase, standardization through harmonization of the language and terminology should bring substantial benefits. During the next phase, measurement and test methods and associated instrumentation can be standardized to assist their adoption into process and production technology. The final stage is then concerned with product standardization to achieve the familiar aims of rationalization, interface compatibility and reliability.

Europe. That international standardization should have clear priority over national and regional standards was confirmed by the European Economic Community (EEC) last year (7). Dramatic changes in standardization have taken place in Europe, where measures to develop a single market and to open up public procurement depend heavily on the availability of European standards. These standards are mainly developed by CEN (European Committee for Standardization) and CENELEC (European Committee for Electrotechnical Standardization). CEN and CENELEC have concluded agreements with ISO and IEC, respectively, for regular discussion of their work programmes with a view to avoiding overlap and deciding where the work should take place. In Europe, the emphasis is to unify the European input to international standards and to adopt international standards or *de facto* international standards.

Membership in European standards committees is open to EEC and EFTA countries, currently 18 altogether. An important feature of European standardization is that while agreement on technical content in committees is reached by consensus, adoption of the standard is by weighted majority voting. Furthermore, adopted standards must be implemented as national standards, regardless of the way the national member voted, and any conflicting standards have to be withdrawn.

Japan. Among developed countries, Japan has one of the most rigorous standardization activities on advanced materials. An extensive survey of standardization needs and feasibility of standards development in industry has been carried out recently (8) under the Japanese Industrial Standards Committee (JISC) covering the fields of metals, high polymers, ceramics and user needs. The need for 927 standards in advanced materials has been identified, of which 685 should be developed within the next 10 years. Of particular relevance here is the recommendation of the Committee that terminology, testing and evaluation methods should be given priority.

Following the recommendation of the Committee, a five-year plan was launched in 1991 to promote industrial standardization. The highlight of the plan is Japan's new policy for greater cooperation with ISO/IEC activities. Specific examples of Japan's new initiatives in advanced materials standardization through ISO/IEC are given later.

The United States. The United States has also substantial involvement and most widely known is the work of the American Society for the Testing of Materials (ASTM). Individuals from any country can participate in ASTM committees which rely primarily on voluntary effort by professionals in industry, including consumers. Standards are developed through a consensus based on broad expertise of organizations interested in the standards. In ISO/IEC, however, the American National Standards Institute (ANSI) is the official standards representative for the United States.

ASTM currently has 120 technical committees covering the following main areas:

- Ferrous metals
- Non-ferrous metals
- Cementitous, ceramic, concrete and masonry materials
- Miscellaneous materials
- Miscellaneous subjects
- Materials for specific applications
- Corrosion, deterioration and degradation of materials.

Finally, although common standards are vital for international trade, one has to go further and address the problems associated with different national testing and certification schemes which can act as technical barriers to free trade. Reliable and mutually acceptable testing and certification procedures are important to achieve the full benefits of standardization. Increasing globalization of trade means that coordination between standards, testing and certification needs to be carefully planned.

Now let us examine standardization activities in two specific materials areas: (a) advanced ceramics standardization and (b) polymer and polymer-composite standardization.

Advanced ceramics standardization. Applications of advanced ceramics in high-technology products require the availability of test and measurement methods for powder properties as well as the properties critical to the design and manufacture of ceramic components and the prediction of their performance. However, the scope for adoption of methods from existing standards proposed originally for porcelain-type materials is limited, and the demand for the establishment of new or modified test methods is high.

Japan was first to publish a standard for these new materials in 1981 (entitled "Testing method for flexural strength (modulus of rupture) of high performance ceramics". The Japanese have since published 10 more standards in English concerned with the measurement of various mechanical, thermal and corrosion properties. The Japanese Industrial Standards Committee has identified standardization of test methods as a priority area and has an ongoing programme containing 95 items selected from an extensive industrial survey (table 1).

In the United States, standardization work in this field started in 1985. ASTM and its Committee C-28 on Advanced Ceramics has a comprehensive work programme in the following key areas:

Properties and performance
Design and evaluation
Processing and characterization
Ceramic-matrix composites
Nomenclature.

In Europe, particularly within the EEC, ceramics standardization came to the fore when the CEC made a mandated request to both CEN and CENELEC for the establishment of a comprehensive programme for setting up European pre-standards (ENV) and European Standards (EN) in the field of advanced industrial ceramics. It was stipulated that the programme should be developed taking full account of international standardization activities in the field.

Accordingly, CEN established a Committee, CEN/TC 184, on "Advanced Technical Ceramics" the scope of which is as follows:

> "Standardization in the field of advanced technical ceramics with specific tasks being classification, terminology, sampling and methods of test. The methods of tests are to include physical, chemical, mechanical, thermal and textural properties for ceramic powders, monolithic ceramics, ceramic composites (including ceramic fibres and whiskers) and ceramic coatings".

TC 194 has to liaise necessarily with other committees and standardizing bodies working in such fields as the biomedical, optical, electrotechnical, construction and aerospace industries. CENELEC has also taken action and set up a new task force (BTTF 63-2), and it is anticipated that its potential work might belong to the fields of interest of a number of technical committees of both IEC and CENELEC.

Of the 18 national standards organizations in CEN, 10—those of Belgium, Finland, France, Germany, Italy, the Netherlands, Spain, Sweden Switzerland, and the United Kingdom (secretariat)—are currently involved in TC 184. The Committee has five working groups as follows:

Table 1. STANDARDIZATION NEEDS ON ADVANCED CERAMICS IN JAPAN

	Standardization Achievable in a Short Period of Time	Standardization Requiring a Somewhat Longer Period of Time	Standardization Requiring a Long Period of Time	Totals
Standardization Especially Necessary	Coefficient of Thermal Expansion Tensile Strength (Room Temperature) Fracture Toughness (Room Temperature) Thermal Shock Resistance Hardness Sampling and Sample Preparation Methods Oxidation Resistance (Room Temperature) Particle Size Distribution (0.1 μm or greater) Particle Absolute Specific Gravity Particle Tap Density Filling Characteristics Creep Strength Sintering Coefficient of Contraction Electromechanice Binding Coefficient Piezoelectric Stress Coefficient Transmission Factor Chemical Component Analysis Cutting Characteristics Thermal Conductivity Total 47	Thermal Conductivity Tensile Strength (High Temp) Fracture Toughness (High Temp) Static Fatigue (Creep) Mechanical Shock Resistance Friction Resistance Non-Destructive Inspections Non-Metallic Impurities Analytical Methods Corrosion Resistance (acid, alkali, salt solution) Maximum Particle Diameter Particle Shape (Aspect Ratio) Fluid Properties (Angle of Repose) Particle Diameter (Powder, Organizer Structure) Granular Body Properties Adhesion and Bonding Properties Components Shock Resistance Critical Temperature (Tc) Critical Current Density (Jc) Critical Magnetic Field (Hc) Meissner Effect Absorption Coefficient Existing State Analysis Crystal Phase and Crystalline Characteristics Fluidity Modulus of Elasticity Poisson's Ratio Total 39	Design Standards Assurance Testing Particle Size Distribution (0.1 μm or less) Secondary Particle and Aggregation Properties Powder Forming Characteristics Extrusion and Forming Properties Surface Phase Evaluation Grinding Characteristics Grindability Cutting Characteristics Friction Resistance Fatigue Crystal Volume Determination Form Determination Shapeability (Forming Characteristics) Granular Body Particle Size Granular Body Density Granular Body Strength Sintering Characteristics Bending Strength Tensile Strength Compressive Strength Torsional Strength Shearing Strength Multiaxis Strength Thermal Shock Fatigue Erosion Resistance Bonding Strength Total 38	124
Other needs	22	62	11	95
Totals	69	101	49	219

Working Group No.	Title	Convenor
1	Classification and terminology	Netherlands
2	Methods of test for ceramic powders	France
3	Methods of test for monolithic ceramics	United Kingdom
4	Methods of test for ceramic composites	France
5	Methods of test for ceramic coatings	Germany

Details of specific programmes of the working groups to be completed by the end of 1992 are given in table 2. There are also plans for a substantial follow-on activity beyond 1992 in WG3 and WG4 covering some 30 topics.

The only international work related to standardization of advanced ceramics is being done under VAMAS by the G-7 countries (see page 274) and the International Energy Agency Programme by Germany, Sweden and the United States. Based on the VAMAS programme, standards have already been developed for wear test methods of ceramics, and further standardization can be expected for testing dynamic fatigue, hardness, fracture toughness at room and high temperatures, fatigue, and grain-size measurements.

An important initiative that has strong implications for the future standardization programme on advanced ceramics has come recently from Japan: the proposal for the formation of a new Technical Committee in ISO. Voting by member bodies of ISO was completed in July, but the results have not yet been announced.

Polymers and polymer-composite standardization. During the last five years, the drive for harmonization of test methods for polymers and polymer composites has grown steadily, and a number of new initiatives started in the international forum. This is because industry must reduce the cost and time of qualification testing. There is also a need for users of composites to adopt more competitive designs which are currently hampered by the lack of good-quality and reliable design data obtained from standardized methods, particularly for general engineering applications. So far, the aerospace industry, where material costs are less important than performance, has catered for its own requirements.

The formation of the Single Market in Europe, the planned North American Trade Agreement with Canada and Mexico and the United States, and generally increasing worldwide trade in these materials are forcing the pace of change. Standards are needed for advanced polymers, fibres, resins, prepegs, laminates and composites.

The Plastics Committee in ISO (TC 61) has a broad range of activities on reinforced and unreinforced materials, although many of the current test methods in composites are related to glass-fibre reinforced materials. Standardization of materials reinforced with carbon and aramid fibres has not been pursued vigorously, but this is changing. Thus, methods for the determination of density and size, and definitions and vocabulary for carbon fibres have been

Table 2. WORK PROGRAMME OF CEN/TC 184

The work programme of the five working groups has been established as follows:

WG1 Classification and Terminology	ENV BJVJ Classification of advanced technical ceramics
WG2 Methods of Test for Ceramic Powders	EN BJVB Methods of test for ceramic powders: Part 1 Impurities in alumina Part 2 Impurities in barium titanate Part 3 Oxygen content, non-oxides Part 4 Size distribution Part 5 Specific area Part 6 Bulk density Part 7 Compaction properties Part 8 Sintering curve (ENV)
WG3 Methods of Test for Monolithic Ceramics	ENV BJVG Methods of test for advanced technical ceramics: Sampling ENV BJVC Test Methods for monolithic ceramics: Part 1 Dye penetration test Part 2 Density and porosity Part 3 Grain size (ENV) Part 4 Surface texture (ENV) EN BJVD Test Methods for monolithic ceramics: Part 1 Short-term strength Part 2 Elastic properties (ENV) Part 3 Delayed failure (ENV) Part 4 Hardness EN BJVH Test Methods for monolithic ceramics: Part 1 Short-term high temperature strength Part 2 Load deformation Part 3 Thermal shock tests EN BJVF Test Methods for monolithic ceramics: Part 1 Thermal expansion Part 2 Thermal diffusivity Part 3 Specific heat (ENV)
WG4 Methods of Test for Ceramic Composites and Reinforcements	ENV BJTV Test Methods for ceramic composites: Part 1 Tensile strength Part 2 Compressive strength Part 3 Flexural strength Part 4 Shear strength ENV BJVL Test Methods for ceramic composites: Part 1 Thermal expansion Part 3 Thermal conductivity Part 4 Specific heat Part 5 Density (of composites) ENV BJTZ Test Methods for ceramic composite reinforcements: Part 1 Size level Part 2 Linear mass Part 3 Filament diameter Part 4 Tensile strength of filament
WG5 Methods of Test for Ceramic Coatings	Definition of thin coatings Definition of thick coatings Guidelines for sampling and testing Chemical composition determination Coating thickness determination Characterisation of the morphology Characterisation of the microstructure Characterisation of the adhesion Coating hardness determination Residual stress distribution determination Elastic constants determination Quasi-static mechanical properties (tensile-, compressive- and flexural-strength) Fatigue properties Thermal shock resistance Determination of thermally induced strains and stresses Wear resistance Corrosion resistance

standardized recently. Also, as existing standards become due for revision, advanced composites are being included, such as laminate test methods (ISO 527) and test panel manufacture (ISO 1268) to cover fabrication routes such as autoclave, filament winding, pultrusion and contact and spray moulding. ISO TC 61 operates with ten subcommittees (SC) with nearly 65 working groups as shown below.

Standardization of composites in CEN has gathered new momentum in the last 12-18 months. Unlike ISO, ASTM or Japanese Industrial Standards (JIS), standards in Europe are divided into "aerospace" and "general" series. To avoid duplication and waste of resources, before a new standard is developed, careful consideration is given to adopting existing ISO standards, followed by adoption or modification of EN - Aerospace or existing national standards in Europe. Importantly, CEN is also keen to ensure that only methods supported by evidence of validation over the applicable range are accepted.

ISO/TC 61 Subcommittees	
SC1	Terminology
SC2	Mechanical properties
SC4	Burning behaviour
SC5	Physical-chemical properties
SC6	Ageing, chemical and environmental resistance
SC9	Thermoplastics materials
SC10	Cellular materials
SC11	Products
SC12	Thermosetting materials
SC13	Composites and reinforcements

The relevant committee in Europe is CEN TC 249 (plastics) with a secretariat in Belgium. It has five subcommittees as shown below.

Subcommittee No.	Title	Convenor
1	Plastics materials and test methods	Sweden
2	Composites reinforcements and prepegs	France
3	Semi-finished plastic products	Germany
4	Cellular materials	United Kingdom
5	Plastics for packaging	Italy

Each subcommittee is served by working groups. For example, in SC2 there are five working groups: WG1 is responsible for all small-diameter fibres (carbon, glass and aramid), WG2, -3, and -4 are responsible, respectively, for aligned reinforced thermosets, random reinforced thermosets and all reinforced thermoplastics, except short fibre systems (which are covered by SC1). Test methods applicable only to specific materials were covered by WG2, -3, and -4, but WG5 is responsible for test methods which are applicable across the range of materials covered by WG2, -3, and -4.

Various trade and industrial organizations with strong interest in composites have been actively pressing for standardization. Most notable in this context have been SACMA (Suppliers of Advanced Composite Materials) in the United States; AECMA (European Aircraft Manufacturers Association); ACOTEG (conglomerate of MBB, Aérospatiale and British Aerospace); and ETAC (European Trade Association of Advanced Composites Materials Suppliers). That there is considerable scope for harmonization can be seen from table 3 which contains a comparison of standards specifications for some commonly required test methods (9).

In some cases, widely acceptable standards cannot be generated before certain key issues related to the test methods are resolved by pre-standards research. Examples include the VAMAS work in the areas of creep, delamination crack growth and fatigue testing of composites.

International collaboration in pre-standards research

Leaders of the major OECD countries recognized the advantages of a concerted effort in advanced technologies for economic growth and employment as early as 1982. One of the initiatives to result from this is a collaborative activity known as VAMAS—the Versailles Project on Advanced Materials and Standards. It operates under a Memorandum of Understanding (MoU) signed by the Group of Seven Economic Summit nations (Canada, France, Germany, Italy, Japan, the United Kingdom and the United States) and the Commission of the European Communities. The underlying theme of VAMAS is to assist in the removal of trade barriers by encouraging the development of standards from a commonly agreed technical base.

Research is undertaken on a work-sharing basis, without any central funding, towards the development and validation of test methods, databases, guidelines and terminology, and their overall scope encompasses any enabling research which is required as a precursor to the drafting of standards for advanced materials. Emphasis is placed on pre-standards measurement research, intercomparison of test results and consolidation of existing views on priorities for standardization action.

Nearly 60 projects have been initiated so far and these are grouped into five technical themes covering fifteen Technical Working Areas (TWAs) as follows:

Theme 1: Metals and metal-matrix composites

TWA6 Superconducting and cryogenic structural materials
TWA11 Creep-crack growth
TWA13 Low-cycle fatigue

Table 3. REVIEW OF POTENTIAL FOR TEST METHOD HARMONIZATION

[C=carbon fibre, G=glass fibre, A=all fibres, P=plastics, *=drafts, SRM=SACMA, AITM=Airbus Industries, ACO=ACOTEG, CRAG=Composites Research Advisory Group (for Aerospace), UK

Test	Methods	Assessment
1 Longitudinal Tension (0°)	ISO 527(P), ISO 3268(G), EN 2561(C)*, EN 2747(G)*, ASTM D3039(F), JIS 7073(C), CRAG 300(F)	Normally straight tabbed specimen. Tab design and material different. 1 or 2 mm thick and between 10 and 20 mm wide. Different moduli measurement methods. Harmonisation started. ISO draft
2 Transverse Tension (90°)	EN 2597(C)*, ASTM D3039(F), JIS 7073(C), CRAG 301(F)	As above but 2 mm thick and 10-25 mm wide. Harmonisation started. ISO draft
3 Multidirectional Tension	ASTM D3039(F), CRAG 302(F), ACO/TP/14	Similar methods except that CRAG includes any ±θ. ISO 527 Part 4 may cover
4 Longitudinal Compression (0°)	ISO 8515(G), ISO 604(P), EN 2850(C)*, ASTM D3410(F), ASTM D695(M), CRAG 400(F)	Similar philosophy (except D695) but differences in gauge area and support jig. 6.35-12.5 mm wide and 2-4 mm wide. More difficult area to harmonise because of many support jigs. CEN new draft
5 Transverse Compression (90°)	ASTM D3410(F), ACO/TP/8	Both compression options as for Test (4). CEN new draft
6 Multidirectional Compression	CRAG 401(F), ACO/TP/14	Similar specimen geometries as Test (3)
7 Flexure	ISO 178(P), EN 63(G), EN 2562(C)*, EN 2746(G)*, ASTM D790(P), CRAG 200(F)	ASTM and JIS include 4 pt. Older standards (eg ASTM) have a range of thicknesses, later 2 mm but EN(G) is 3 mm. CEN new draft
8 Interlaminar Shear	ISO 4585(G), EN 2563(C)*, EN 2377(G)*, ASTM D2344(F), CRAG 100(F)	Normally 5/1 span/depth. ASTM range of thicknesses, EN(C) is 2 mm but EN(G) is 3 mm thick. CEN new draft. CRAG 2 mm
9 In-plane Shear	ASTM D3518(F), CRAG 101(F), ACO/TP/9, AITM 10002	Normally 2 mm thick. ASTM and CRAG 25 mm wide and ACO is 16 mm. AITM 25 mm x 1 mm. CEN preparing new draft
10 Open Hole Tension	CRAG 303(F), ACO/TP/12, SACMA SRM5(F), AITM 10007, DIN 65559	Same specimen width/hole diameter (6/1) for metric and non-metric versions except AITM 5/1. Hole diameter 6 or 6.35 mm CRAG has a range for both values
11 Holed Compression	CRAG 402(F), ACO/TP/11, SACMA SRM3(F), AITM 10008, DIN 65560	As above for tension
12 Compression After Impact	CRAG 403(F), DIN 65561 AITM 10010, SACMA(ASTM)(F)	Boeing test method (ASTM R-R) gaining acceptance, in DIN draft

TWA15 Metal-matrix composites

Theme 2: **Polymers and polymer-matrix composites**

TWA4 Polymer blends
TWA5 Polymer composites
TWA12 Efficient test procedures for polymer properties

Theme 3: **Ceramics and ceramics-matrix composites**

TWA3 Ceramics
(TWA14 see under Theme 5)

Theme 4: **Test Techniques (non-material specific)**

TWA1 Wear test methods
TWA2 Surface chemical analysis
TWA7 Bio-engineering materials
TWA8 Hot-salt corrosion resistance

Theme 5: **Materials classification and data**

TWA10 Materials data banks
TWA14 The technical basis for a unified classification system

In the first phase of VAMAS, which was recently completed, over 500 people participated from industry, Government and academic organizations from the member countries. Additionally, with the unanimous agreement of member nations, researchers from eight non-summit countries—Austria, Belgium, Denmark, Finland, the Netherlands, Portugal, Sweden and Switzerland—also participated in the technical areas. Materials included in the work of VAMAS are wide-ranging, and all the major classes of materials are included in the characterization and measurement work covering thermal, mechanical, electrical and environmental behaviour.

The output of VAMAS forms a significant body of publications in scientific journals and general literature, but the work has clearly led to guidelines for testing and analysis, standards, codes of practice, data transfer formats and reference materials (10). Important and working links have also been established among researchers in member nations, which means that cooperation on broader fronts in advanced materials R&D can be fostered.

Based on the overall success of VAMAS in the first phase, the MoU was extended for another five years. In view of the potential to influence international standardization of test and measurement methods, ISO has recently signed an MoU with VAMAS to publish suitable VAMAS outputs as a series of "Technology Trend Assessment" documents to accelerate the dissemination of key information. An MoU with IEC is also being considered. It is clear that international collaboration and cooperation can have enormous benefits in developing and rationalizing advanced materials testing and evaluation.

It may be useful to discuss one or two specific examples of VAMAS activities in this context. Technical Working Area 2 deals with surface chemical analysis techniques: auger electron spectroscopy (AES), X-ray photoelectron spectroscopy (XPS) and secondary ion mass spectroscopy (SIMS), all of which are used throughout the world for research and development of materials and high-technology products. VAMAS became active because of a need to produce widely acceptable reference procedures, reference data and reference materials as a basis for standards for surface chemical analysis. There was also the recognition that considerable effort was being made separately in Europe, Japan and the United States to overcome similar key technical problems and that cooperation would bring considerable synergistic benefits.

Work in this area is led in the United Kingdom by NPL, with the participation of nearly 100 laboratories from about 10 countries. Already the VAMAS work has produced recommendations for standardized energy and intensity calibration methods used for measuring chemical compositions and concentrations in AES and XPS. Normally, spectra from commercial spectrometers are distorted from the true spectrum by the instrument transmission function, which depends on the electron energy and the instrument settings. To calibrate these functions, NPL has established a reference spectrometer with traceability to primary standards; this provides true spectra and, hence, true chemical compositions and concentrations, for defined reference materials (11).

Thus, on the same specimen, one can now obtain consistent and mutually recognizable results throughout the world. With instruments calibrated to national primary standards, it should be possible to develop reference data banks for wider use internationally. To this end, the VAMAS group has already developed a standard data transfer format to aid the process.

The work of the TWA has led to wider international interest and activities; in fact, a new Technical Committee on Surface Chemical Analysis (TC201) was recently set up by ISO, with the secretariat based in Japan. VAMAS has close links with the ISO Committee, and the transformation of VAMAS results into international standards will be accelerated.

A different kind of programme, but of equal significance, is being undertaken by VAMAS TWA14. Supported strongly by industry in the member countries, the TWA is developing a sound unified classification system for advanced ceramics. At present materials producers and users adopt a variety of schemes for different purposes: manufacturers to promote products, develop design databases or assess markets; trade organizations and Governments to collect statistics or market values; or customers to have a means of specifying a class of product.

Despite many problems of nomenclature, complexity of chemical description and coding, VAMAS is in the advanced stages of producing a draft scheme. This will be considered for standardization through CEN and other standards bodies.

Strategic considerations for the Middle Eastern economies

Advanced materials provide a unique opportunity for industrial and economic development in the ESCWA region, which is rich in natural resources. Currently, the strength of the countries lies primarily in the production of raw materials, and one needs to consider carefully the potential involvement in the follow-up aspects of materials. Here, it would be instructive to consider the materials chain in which one moves from raw materials to processed raw materials, enabling industries, materials user industries and also the service industries. For example, the chart in figure 2 shows the involvement in the United Kingdom of various sections at different points on the chain (12).

Thus, it would be necessary first to examine the options for building or strengthening sectors of the economy in the region based on wider considerations. This would enable one to identify whether emphasis should be placed on the supply side of advanced materials (by adding value to the raw materials) or the user side, or both in certain areas. This can help to determine the requirements or targets for imports and exports of advanced materials and their products. As already mentioned, testing and evaluation has a fundamental role throughout the materials supply and user industries, but the requirements are different. Thus, priorities for action should be set on (a) the areas of materials and products and (b) the types of testing and evaluation, for the region; however, the development of such a plan must be integrated with the investment scenario in materials technology as a whole.

Appropriate capability in materials evaluation technology should be built with cooperation between industry and Government. Generally, the Government can be expected to take the lead in the development of an infrastructure that will adequately support industrial test and measurement activities. Industry is reluctant to invest in development of techniques and methods which are generic or have wide applicability, so these often require government support; testing and generation of data on specific materials using standardized methods should be the responsibility of industry.

As standardization of advanced materials, particularly in the area of testing and evaluation, can bring considerable benefits to materials producers and users, the development of a suitable set of standards should be reviewed as early as possible. Any work programme must take full account of international developments to avoid duplication of effort and generation of conflicting standards. Also, because trade in materials and their products is truly international in character, it is vital that specifications, codes of practice and standards are developed on an international basis wherever it is appropriate to do so. However, regional action is important and should provide an effective platform for participation in international activities as well as support the development of purely national/regional standards in suitable areas.

Pre-standardization research will be needed to aid the development of standards and is best carried out in a cooperative way. Mechanisms already exist in the developed countries, and the ESCWA region should cooperate with UNIDO to benefit from their wider involvement with the developing and developed countries in this area.

For the successful development of an effective capability in materials testing and evaluation, considerable investment in physical and human resources is needed, but this must be done in a coordinated and planned manner with strong liaison between Government and industry. Care should be taken to avoid a structure which is too widely distributed and unconnected because this can be inefficient.

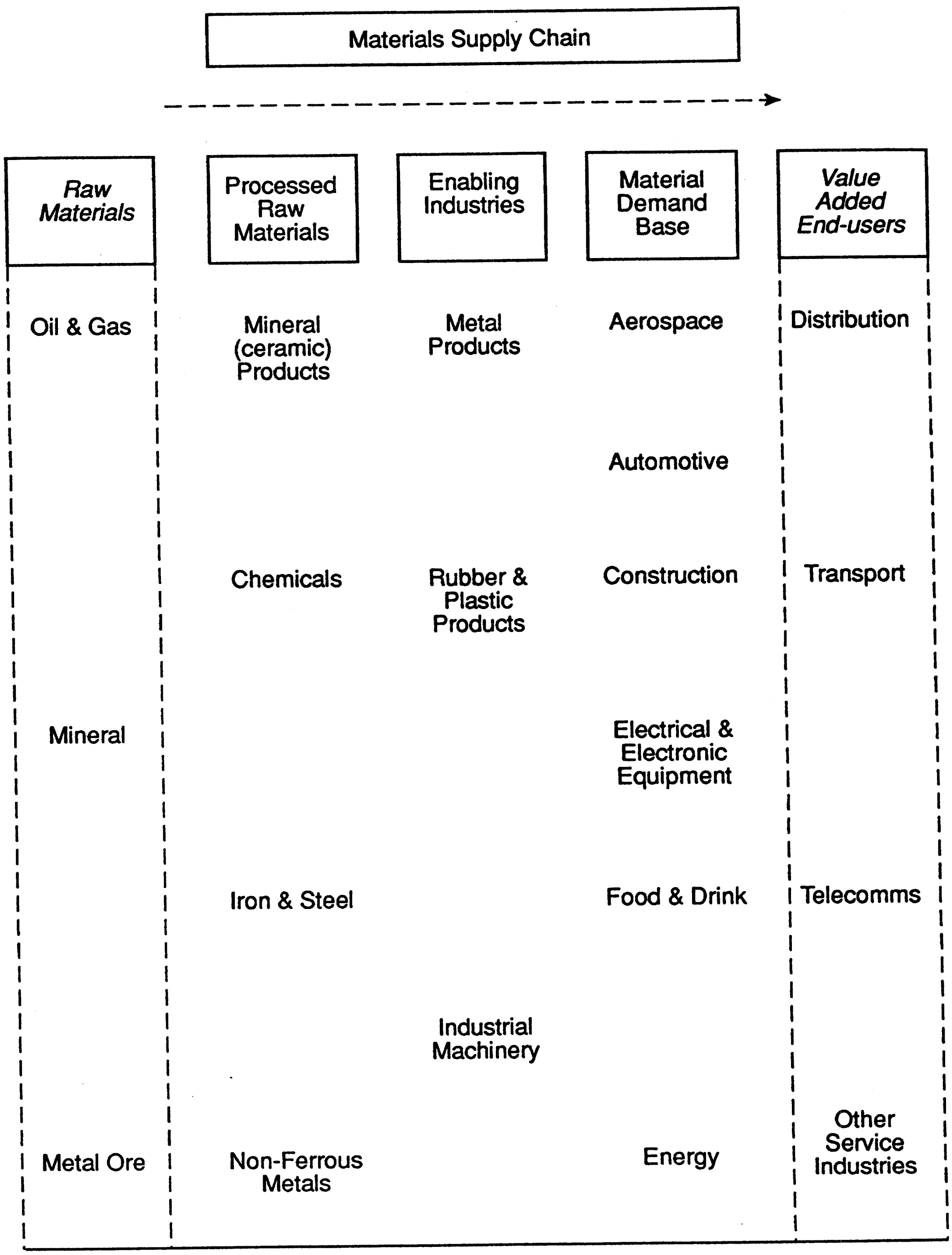

Figure 2. SECTORS OF THE ECONOMY WITH MATERIALS INTEREST

One option is to aim for a number of key centres, building on existing institutions, which can operate in a complementary and collaborative fashion to provide a basic framework. It should be well publicized for wider dissemination and service to industry and means of technology transfer should be considered at an early stage. Professional, trade and industry associations have an important part to play in this context.

Availability of trained personnel is a key issue, and an assessment of future requirements needs to be identified at an early stage. Good links with other countries and established institutes could assist considerably in meeting the goals for manpower supply as well as technological assistance.

REFERENCES

1. Dyson, B.F., Lohr, R.D. and R. Morrell (Ed). "Mechanical Testing of Engineering Ceramics at High Temperatures". Elsevier Applied Science, (ISBN 1-85166-036-4) 1989.

2. Roebuck, B., Lord J.D., Cooper, P.M., and L.N. McCartney. "Tensile Properties, Data Acquisition and Analysis for Particulate and Fibre Reinforced MMC". ASTM Symposium, Miami, 17-19 November, to be published in J Testing and Evaluation, 1993.

3. Roebuck, B. "Parabolic Curved Crack Fronts in Fracture Toughness Specimens of Particulate Reinforced Al Alloy MMC". Fatigue and Fracture of Engineering Materials and Structures, 15(1), 13-22, 1992.

4. Wilson, D. W. "Materials Characterization: Impediment to Expected Growth of the Composites Industry?" CCM Seminar Series, University of Delaware, Newark, Delaware, USA, 1989.

5. Quinn, G.D. and R. Morrell. "Design Data for Engineering Ceramics: A Review of the Flexure Test". J Am Ceram Soc, 74, (9), 2037-66, 1991.

6. International Organization for Standardization (ISO). "A Vision for the Future" ISBN 92-67-10154-4, 1990.

7. Commission of the European Communities. "Standardization in the European Economy", a communication from EEC, 1992.

8. Japanese Industrial Standards Committee (JISC). "Standardization of Advanced Materials—Summary Report of the Special Committee on Standardization of Advanced Materials". Agency of Science and Technology, Japan, 1988.

9. Sims, G.D. "Standards for Polymer Matrix Composites: Part II—Assessment and Comparison of CRAG Test Methods". NPL Report DMM(M)7, 1990.

10. Versailles Project on Advanced Materials and Standards (VAMAS). Bulletin No. 12. Published by National Physical Laboratory, Teddington, United Kingdom, 1990.

11. Seah, M.P. and G.C. Smith. "Surface Interface Analysis", 15, 751, 1990.

12. Roy, R., Timothy, S.P., and D.A.J. Vaughn. "Materials Exploitation in the U.K." Published by the Centre for Exploitation of Science and Technology, 1991.

Discussion of Part One, Paper Three

Mr. R. Bassyouni:

Q. I would like to raise a question concerning some points in the testing equipments for composite materials for vital, designed parts. We have spoken about creep, Young's modulus within the test results you have obtained. I know it is quite different from the scope of testing, but you have collected so much information and so many results, perhaps you could give us some more information.

Ans. Basically, the type of work that we have been concentrating on is working out the measurement method; for example, how can you measure Young's modulus, which gives you the confidence to design for safety and for health or for good and reliable performance? But the type you are looking for is perhaps what industry requires in specific situations.

Mr. Mohammad Jarrah:

Q. My first question relates to the scatter of measurements related to composite materials. For most of the time, such scatter is linked to the manufacturing process itself because you cannot repeat the same manufacturing process. The large scatter in the data is due to human involvement in the process. The second question I would like to ask is about the role of institutions and universities in the Middle East or in the Arab countries and their interaction with decision-makers. Here one can observe that most of the time our politicians or decision-makers are not technocrats: they do not follow up progress in technology. Therefore, they are neither well informed nor confident when they make decisions about new technologies. It is therefore interesting to see how you envisage the interaction between universities and institutions and decision-makers.

Ans. I think the institutions have a clear role in many areas, and one can see the universities at the front line, where they are gaining new knowledge and developing new bases. But when it comes to making measurements, we must have a framework that the whole of industry can depend on. You must then go to, perhaps, an organization like ours in the United Kingdom, which is the National Physical Laboratory, so that all measurements can be traced back to the standards we develop and the standards we keep and maintain, and I think that is the crucial thing that you must have: an institution or institutions which are clearly responsible for this kind of activity and from which people can obtain back-up information in critical cases. So what we are trying to do is actually helping laboratories throughout the country to come up to standard. There has been laboratory accreditation by having standards which are checked against our standard and so on, taking against our methods, and we have, for example, in ceramics testing, the most accurate instrument which will give you the reliable result within $\pm 2\%$ of whatever, but that can be used for all purposes. I think you have got to bear in mind that you do not want to have measurement methods which are expensive. You have to have horses for courses, meaning that, if you want to have a cheap test done and as long as that serves your purpose, that is what you should be doing; if you are doing more, then you are wasting time and money.

Mr. Zeki Fattah:

Q. If I may just correct this point: he was asking about the interrelations which could be established between universities and testing institutions? How can the fabric be woven between the two?

Mr. Mohammad Jarrah:

Q. The purpose of this workshop is to introduce advanced materials into the region. This is one of the responsibilities of decision-makers. In our region, either there is no link between universities or science institutions and the decision-makers, or the link is weak. So how can we build that confidence? How can we surround policy-makers with scientists who are up-to-date in their knowledge? Often politicians see the world through the eyes of their advisors.

Ans. Are you talking about how to convince your politicians to set up institutions which will have the test and measurements capabilities, or are you talking about the central institutions which act as the focus for all the test and measurement activities? I think it will come out in the workshop that testing of innovation, in my view, is an important, basic thing that you need.

Mr. Zeki Fattah:

Which fits into the further aspect of the decision-making process.

Ms. Wafa Abdel-Fattah:

Q. I would like to ask about the non-destructive testing standards. What could you tell us about the non-destructive testing standards?

Ans. Non-destructive evaluation has got standards for the classical ceramics, but the techniques are still being developed to give sufficient reliability. Many of the standards are not of as good quality as you need for the technical ceramics side. Perhaps they are adequate for the white ceramics, which need a much greater application, but the industrial scene is a very important area, as Mr. Lexow and Mr. Czichos's review showed. They both indicated that there was demand for R&D and analysis.

Mr. R.S. Ganapathy:

Q. I have one question related to the earlier point which was raised by an earlier speaker: it is about this fascinating field of the standards. I think there is a profound dilemma which many third world countries will face because of world developments. One is the need for standards. This is very clear. There is a globalization of export market; a Single European Market is emerging; it can impose its standards around the world. So many developing countries will have to use these standards. There will be the dominance of European standards around the world. But there are two kinds of problems. One is excessive standardization, which tends to curb initiative and creativity, particularly in the context of advanced materials. We look at advanced materials and we see that the distinction between materials and products is actually disappearing. The second is that we have to look at things in terms of competitiveness, I saw ISO 9000; there are more procedures in relation to products to perform which are very problematic, and I have a feeling that there is a genuine fear that this particular trend might, in fact, reduce the competitiveness of third world products, because it will increase costs, as the standards have been developed in another context for different types of applications. To establish that kind of testing facilities, standardization, equipment, procedures, certification, mechanisms might, in fact, reduce the competitiveness. This is the dilemma. On the one hand, a globalization is taking place; on the other, the nature of advanced materials in the end uses and the local structure may well make it very difficult for many developing countries to cope.

Mr. Mohammad Jarrah:

Q. Do you have standards for ecological equilibrium and environmental safety within your institute?

Ans. Regarding the environmental side, I am not very familiar with the environmental standards. But I am pretty sure that there will be many activities on developing new standards for environmental control. I would like to thank Mr. Ganapathy for raising one or two important issues earlier. I think the question of standards threatening innovation is a very important one because there are standards for conventional materials. If you think about steel, people are still developing standards, but those standards are for market protection.

Already, you have various suppliers throughout the world, and what they are looking for is a fair share of the market. Everyone wants to play on a level playing field and get his fair share.

When it comes to advanced materials, I would argue that the standards actually help me to create the market, one of the many reasons why you are not getting the take-off as fast as possible is that you do not have widely acceptable standards; you do not have the facility for getting materials from one country, making a product in a second and selling it in a third. So having an international standard would help enormously, and you will find details for this in my paper. ISO had a very high-level workshop or review on standardization for advanced technologies called "A Vision for the Future."

I referred to it in my paper. But what we want to conclude is that advanced technologies need standards and the standardization process would have to be quite different and much faster and so on. The high-level workshop also came to the same conclusion, i.e. that you need standardization to create markets and develop markets in these particular instances. Regarding your other point, I think the issue is significant here because you cannot simply say we would accept or we would work towards international standards. You may not be using the same materials for the same applications for the same process design, same process of production and so on, and really you have got to think very carefully about where are you going to concentrate? Is there an international activity there? Is it for the same purpose? But I would say that, if in the same area you have an international activity, then you will do wrong to keep out of it because international standards are becoming more and more important. Although I did not have time to discuss it in detail, what is happening is that even between Europe and the United States there is now agreement that international standards take priority. So Europe is developing many standards, but wherever there is an international standard they will not duplicate it. What is crucial here is that one should think very carefully: do you need a standard for a country, a standard for the region, or a standard internationally? A standard for the country should only be thought of in a very narrow range of cases, and then you want to talk about the region, I would think it would be an ideal case for thinking about some regional standardization, and regional cooperation would be marvellous for you to develop or perhaps even have a regional input to the international standardization activity. That way, you make better use of your scarce resources. You have as a group an input which will be much stronger in the international forum than it would be perhaps on an individual basis.

Paper Four

DEVELOPING AN EDUCATION AND RESEARCH STRATEGY FOR NEW AND ADVANCED MATERIALS TECHNOLOGY IN THE ESCWA REGION

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Abstract

Based on European examples of collaborative industry-government-university arrangements, this paper summarizes the analogies required to develop a strategy for materials education and research and describes programmes which could be utilized in the ESCWA region.

Introduction

Since the move away from traditional metallurgy as a university course in many countries there has been a debate in progress on what should be taught and researched at universities. A simple market-driven approach leads to a stop-go mentality as industry and Government switch their requirements on and off. Given that universities and other institutions of higher learning and research are to some extent the focus for a nation or region, it is incumbent upon them to debate this issue and to propose ways to go forward. This paper is based on the author's experience of this debate and on how it has developed in the United Kingdom and Europe. The features that are important for the Middle East will then be highlighted.

A. NEED VERSUS DESIRE

Advanced materials are seen as very important to many economies, and yet there is little analysis of what is required to effect a strategy suitable for a specific country. Many are drawn by the high added-value and prestige while failing to count the cost of entering the field. It is to be noted that several large international companies such as British Petroleum (BP), Budishe Anilin und Soda Fabrik (BASF) and Imperial Chemical Industries (ICI) are pulling back on their advanced materials programmes because of the high cost. Likewise, the announcement by Boeing not to consider low-density aluminium-lithium alloys for the next generation of air frames is seen as a significant setback, and it has to be argued whether the large investment in these materials was justified. A similar story emerges for lightweight metal-matrix composites. Given the very wide vista of new materials available, from thin ceramic superconductors to lightweight space structures, areas chosen for research and training have to be selective. The question is, how is such a selection made?

For example, in the United Kingdom, some 500 people graduate each year in materials, of which about 100 specialize in metallurgy. British Steel Corporation (BSC) claims to have a need for 140-160 ferrous metallurgists a year to service their research, development and production units. There are only 1 or 2 university departments (out of 15), however, that would claim to give a thorough grounding in ferrous metallurgy. Clearly, there will be a major shortfall in BSC's needs. Two important factors are involved.

(a) Can universities satisfy regional industrial needs?

(b) If the answer to (a) is yes, how can good applicants be persuaded to take these courses?

A simple expansion of places in courses results in a very long tail of poor students who hold back the good ones who will eventually take up key employment positions. Analysis of

United Kingdom graduates demonstrates that the majority of personnel who stay in materials-related employment go into user- and applications-based industry. The first question that a teacher must address is whether a course is producer- or user-led. In the former case, details of raw materials, extraction, synthesis and finishing treatment are required. In the second, knowledge of how design philosophy interacts with materials selection, mixed material structures, testing and competitiveness is important.

Underlying these two extremes is a critical feature that is not always considered, especially by countries that have an abundance of raw materials. A subtle but significant change is taking place in that very few materials have such special properties that their market is guaranteed. Users are tending (especially in the high added-value area) to put critical materials only where they are needed. The shift from a materials-led to a design-led mentality is well advanced. This fact has been acknowledged by the steel and aluminium countries in Europe, and special awareness packages are in place which will be described below.

B. SCIENCE OR ENGINEERING?

The debate over whether materials education should be science- or engineering-based will never be resolved since as a subject, it truly bridges fundamental quantum mechanics to large engineering structures and processes. The unity of applied science on the basis of fundamental subatomic science is not questioned.

It is necessary, however, to acknowledge that most students will not easily be able to make the transition from the fundamental to the applied side of the subject, and indeed very few will have the inclination to do so after their formal training is complete. The kudos attached to the fundamental approach is very high for academics, as they identify with physicists, chemists and mathematicians. However, is this attitude a luxury? The cost of training and research is high for this type of approach; much of the required equipment in this field costs over $1 million per item. Conversely, the emergence of finite element analysis, neural networks and continuum mechanics, which treat materials as near homogeneous "lumps" of material have given rise to many instances of poor specification and ultimately of failure. To summarize we can define the various approaches as:

Materials science
Materials design
Materials engineering
Materials systems

These are placed in an order to demonstrate the variety of approaches that can be taken in teaching and research for courses that are not based on primary processing. For this particular group, a processing chain can be derived which has similarities with chemical engineering and mineral engineering approaches. In this instance, there will be a variation from fundamental thermodynamics and heat transfer to a systems approach looking at flow through plant and the effect on environment. In making it clear that there is no single view, it is also necessary to appreciate the contribution of management and manufacturing courses to the training of a well-rounded professional engineer in the materials field.

There is clearly no "right" answer and a portfolio is required with a balance being decided by national and regional needs. One major concern in determining this balance is to give each aspect equal weight and support. There is considerable evidence that the scientific aspect is more highly regarded in academic and governmental circles while the systems approach attracts management support in industry. The middle grounds of design and engineering are equally critical and contribute to the right use of materials in user industries. The balance is therefore determined by student interest, current industrial need and the planned strategic requirements of a country. Coupled with this, it is necessary to ensure that new ideas and techniques are continuously upgraded and discussed. Too often countries develop a short "high profile" strategy and then fill their university positions with tenured personnel. This effectively gives rise to a 10-15 year period of activity followed by fossilization. Another common mistake is to over-endow teaching and research organizations with expensive state-of-the-art equipment which is difficult to maintain and requires continuous upgrading. In this case museums are quickly created and little original research can take place in the medium term.

C. Focus or diversity?

Materials research is extremely expensive and there is considerable pressure on government funds to support one or two centres to bring them up to speed on an international front while letting other centres make do as best they can. Experience from the United Kingdom where so-called "Interdisciplinary Research Centres" have been created have not been successful for several reasons:

(a) Difficult to manage—academics tend to be free agents and are not trained to manage large centres. The imposition of outside management creates resentment;

(b) Centres of excellence are not equipment-based. There is a marked reluctance of good people to move once they have established a working environment which is conducive to their needs;

(c) Continued funding is not guaranteed. The transference of funding from government to industry puts centres in the position of having to vie with other contract research organizations for funds;

(d) Centres are not adaptable to changing circumstances—for example the United Kingdom Centre of Advanced Materials is largely based on what were the apparent needs of the European aerospace industry. Worldwide there has been a cutback in this area, leaving much of the research in a position whereby its application is not obvious in the medium term;

(e) A tendency to focus on high-profile topics. Generally, government support is directed towards obtaining the maximum publicity for these large investments. Traditional materials-based industries find it difficult to put together projects that attract support.

Another experiment which has been tried in Denmark is the creation of centres based on several institutions and industries. Six materials centres have been created, namely:

Powder metallurgy (PM)
Ceramics

Surface science
Dry surface technology
Wet surface technology
Composites

Each centre is managed by one person and directed by a management committee consisting of academics and industrialists, some of whom are not directly involved in the centre. The result has been better than the United Kingdom experiment, although it has resulted in a rather disjointed approach to the topics, with little attempt to integrate programmes. Another problem has been the seeming inability of some academics and industrialists to understand and therefore direct programmes meaningfully. In the powder metallurgy programme, for instance, about $1.5 million per year is used to support progress on the following:

Advanced atomization
Nanophase powders
Powder injection moulding
Sintering of corrosion-resistant stainless steels
Development of dispersion strengthened metal matrix composites
Creation of design data for PM structural parts

Although this is a highly laudable list, it is clear that the actual contribution (given the high cost of research in Denmark) to each project is not great enough to ensure success in terms of contribution to the national economy; even at this level of concentration, funds are spaced too thinly.

Other models include specially promoted programmes to which consortia of industry, research organizations and universities can bid. Success of these depends on good relations among all partners and an understanding on the constraints placed on each party when reviewing the project.

It is possible to define research as proactive and reactive. In the first instance new ideas are created and end applications are not always obvious. The reactive area can either be to understand something or a process which has been chanced upon or has grown up, or can be due to "market pull". A good example of the latter is the melt extraction of cheap stainless steels for concrete reinforcement. The melt extraction process (figure I) was developed as a casting method for making cheap wires for tyre reinforcement. It consists of dipping a sharp-edged, rotating wheel onto a molten metal bath whereby fibres 150-200 μm in diameter are extracted and freeze on the wheel. As they freeze contraction occurs and the fibres fly off, a novel process which was borne of a market need. Unfortunately, the uniformity of the fibre was insufficient for the application but the process was subsequently used for making stainless steel fibres for high-temperature refractory reinforcement and these are now employed in petrochemical plants. This material is too costly for normal concrete reinforcement. Consequently the author and industrial collaborators focused on cheap sources of high-carbon ferro-manganese and low-grade scrap in order to make a near stainless fibre with similar properties to heavily drawn low-alloy steels that are commonly employed for this purpose. The ability to spray these fibres *in situ* has led to an international demand for this product. In the end a market need pulled through the process and materials.

It is clear from the above that considerable thought is needed if a return on investment in materials research is to be obtained. In most cases, collaboration is essential and thought is needed on how to manage and drive such groups efficiently. However, much depends on the attitude of parties, and this leads back to education and training, combined with the rewards of success for all parties involved.

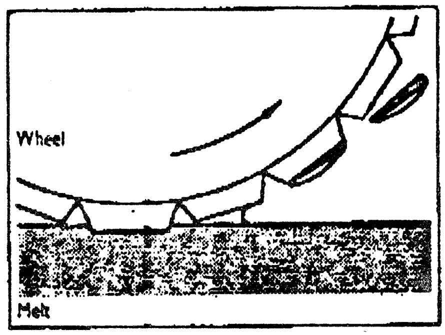

Figure I. Melt extraction of stainless steel fibres for cheap concrete (*Courtesy of* Fibre Technology).

D. Education and Training

The general principles of education and training were stated above. A portfolio of basic scientific and various emerging approaches is required to fit industrial needs and government strategies. A review of the materials courses forming the author's department and others reflects this at the undergraduate level; the following are offered:

Material chemistry (basic science)
Minerals and resources engineering (primary processing)
Mechanical design, materials and manufacture (user industries)
Chemical processing and materials engineering (systems approach)
Materials engineering and electronics (specific user need)
Materials engineering and language (all the above with European languages)

A core course is common to all these and allows efficiency and diversity. A good supply of students is available for materials chemistry since it is a natural extension of the subjects they studied at school. The most popular course, however, is mechanical design, materials and manufacture, in which students can clearly see a well integrated approach and a clear market need for their training. Thus students learn about Total Quality Management and Just-in-Time methodology coupled with advanced materials processing and characterization techniques. The course modules are given in figure 2. However, underlying these details are two important criteria. Before the courses were formulated, several discussions were held with key industrialists and government personnel as to the nation's requirements. The two key criteria were that students must know the basic scientific and engineering principles of the subject, and they must be able to communicate. This latter aspect has had a large influence on educational methodology; a mixture of straight lecturing, examples classes, laboratories, projects and case-studies are used. The last item is especially important for encouraging interpretation and presentational skills. Team and individual projects allow students to practice their management skills and to experience aspects of current research. Although only three years' worth of graduating students have been released, the general impression is that the graduates are highly regarded and have found positions in key user industries. A criticism that the courses were too general has been dispelled by the reaction of industry that it would rather teach the details itself.

Postgraduate training is also in a state of considerable flux, and there is a growing reflection of developments in undergraduate programmes, where interdisciplinarity and collaboration with industry is taking place. While there is a place for independent research

Figure II. COURSE DIAGRAM FOR BENG/MENG IN MECHANICAL DESIGN, MATERIALS AND MANUFACTURE

Qualifying Stage

SEMESTER 1

Introduction to Materials A	J51IMA	Design, Manufacture and Materials 1	H31DM1 (20)
Introduction to Materials B	J51IMB	Basic Mathematics or Intrductory	
Basic Design Analysis	H31BDA	Calculus	

SEMESTER 2

Chemistry of Materials 1	J51CHM	Design, Manufacture and Materials 2	H31DM2
Introduction to Computing	J5AICO	Quanitative Methods	H71QMT
Mechanics of Solids 1	H31MS1	Applied Algebra	HGAEM1

Part I Stage

SEMESTER 3

Strength and Toughness of Materials	J52STM	Design, Manufacture and Materials 3	H32DM3 (20)
Engineering Materials Manufacture	J52BMM	Introductory Calculus or Differential	HGAEM2 or
Mechanics of Solids 2	H3BM52	Equations and Calculus	HGBEM3
Total Quality Management	H7BTQM		

SEMESTER 4

Time Dependent Behaviour of Materials	J5BTDB	Design, Manufacture and Materials 4	H5BDM4
Materials Characterization	J5BMCH	Differential Equations and Calculus	HGBEM3 or
Phase Transformations in Materials	J5BPTM	or Automated Manufacture	H7BAUT

Part II Stage

SEMESTER 5

Materials Under Stress	J5CMUS
Materials Research Project	J5CMRP (20)
Options	(30)

SEMESTER 6

Advanced Alloys	J5CADA
Group Design Project	H33DES (20)
Options, 10 credits from each of groups D, E and F	(30)

Part III Stage

SEMESTER 7

Group Project	J54GPP (20)
Options, minimum 10 credits from each of groups A, B and C	(40)

SEMESTER 8

Group Project	J54GPP (20)
Quantitative Management Methods	H34QMM (20)
Options	(20)

→ M Eng

Part II Stage (B Eng route)

Materials Under Stress	J5CMUS
Materials Research Project	J5CMRP (20)
Options	(30)

Advanced Alloys	J5CADA
Group Design Project	H33DES (20)
Options	(30)

→ B Eng

Figure II. (*continued*)

OPTIONS for PART II (semester 5) and PART III (semester 7) STAGES		
A		
	Corrosion Control Engineering	J5CCCE
	Conservation and Recycling of Materials	J5CCRM
B		
	Machine Dynamics (semester 5)	H3BMDY
	Polymer Engineering	H3CPOE
	Advanced Metal Forming	H7CAMF
	Mechatronics	H3CMEC
	Dynamics of Mechanical Systems (semester 7)	H3CDMS (20)
C		
	Surface Processing	H7CSUR
	Flexible Automated Manufacture	H7CFAM
	Ergonomics in Design (semester 5)	H7BEGD
	Concurrent Engineering	H7CCNG
	Organisaton and Work (semester 7)	H7CORG
	Probabilistic and Numerical Techniques (semester 5)	HGBEM6
	Mathematics for Engineering Management (semester 7)	HGCEMM
	Language	

OPTIONS for PART II (semester 6) and PART III (semester 8) STAGES		
D		
	Composite Materials	J5CCOM
	Materials Manufacturing (Casting & Welding)	J5CMCW
	Engineering Ceramics	J5CECE
E		
	Structural Vibration (semester 6)	H3BSTV
	Component Analysis and Failure Assessment (semester 8)	H3CCAF (20)
	Software Engineering	H3CSOE
F		
	Automated Manufacture (compulsory if not taken in semester 4) (semeste	H7BAUT
	Plant Location and Design	H7CPLD
	Quantitative Decision Making (semester 6)	H7BQDM
	Optics and Lasers in Engineering	H7CLAS
	Business Accounting (semester 6)	H7BBAC
	Financial Appraisal of Projects	H3CFAP
	Language	

leading to a doctorate, the need for well-rounded personnel who are trained in research methods and management, and state-of-the-art techniques and who can communicate with industrial collaborators has been recognized in several countries. This clearly puts demands on both academics and industrial partners involved in the interaction. Senior academics have to display good marketing and management skills in this type of environment. While the industrial interest has been highlighted in the present paper, this approach to education has found widespread support in careers as diverse as technical journalism and marketing to schoolteaching.

E. POST-UNIVERSITY INITIATIVES

The concept of continuous training is embodied in the principles of Total Quality Management. Everyone is a student, including the managing director of a company. A training and research policy must take this into account. Further partnerships and educational programmes have to be developed jointly and require substantial government support if they are to succeed. An outstanding success has been achieved in the United Kingdom by what is called the "teaching company scheme". The concept is based on the type of experience that a junior doctor receives in hospital. Well qualified graduates are employed by a university department yet work and are managed in industry. Academics are expected to attend the company on a regular basis. The graduate's progress is monitored and assessed by a management committee consisting of industrialists, academics and representatives from the government funding agency. Conditions of employment are set by the company, and considerable effort (10% of time) is devoted to training. After two years these associates generally take up middle-management positions and quickly rise.

F. STRATEGY AND COLLABORATION

In this general paper two important aspects have been emphasized:

(a) The need for a national strategy in research and education in materials;

(b) The need for collaboration between all parties if value for money and strategic objectives are to be achieved.

It has been confirmed that blanket funding of ideas and traditional academic teaching in materials is unlikely to meet the needs of either countries with established or emerging materials-based industries.

How can this analysis help the requirements of the ESCWA member countries? While it ill becomes an outsider to suggest answers, some key pointers should be addressed. These start with market needs and progress through research initiatives to education. They are listed here as questions:

(a) What drives new materials developments? The need to shift priming primary raw material or to develop high-value-added products.

(b) Can the internal market support end-use development?

(c) If not, what steps can be taken to ensure that companies are involved in global events (cf. MITI's approach and support of global R&D)?

(d) In view of (a)-(c), is it worth going it alone or looking for international partners?

(e) Few markets are dominated by either one supply or one material. Therefore, do you have any control at all? If not, how can it be obtained?

(f) Does the Government invest in licensing, training and other initiatives in addition to capital items?

(g) Is there a strategic development plan for existing and future industrial projects?

The author believes that these questions highlight what is available to the internal and external markets. Few large companies go it alone, and encouragement is needed to join alliances wherever possible by licensing and joint developments. This approach has been adopted in China, which has a large internal market and a source of strategic materials (e.g. tungsten). Joint developments for two-way collaboration now exist, and the Chinese are seeking to add value to their resources.

Once an industrial strategy is determined then a research policy for research centres and universities can be developed, again based on partnership. There are some key questions that need to be asked in this respect:

(a) What is the current and future mix of the primary, secondary and tertiary processing industries compared to user industries?

(b) Are the user industries internal or external?

(c) If the user industries are external, is it necessary to have a credible research base to support customer needs?

(d) How can individual groups cooperate with indigenous industry?

(e) What type of research is necessary for the short and medium terms?

(f) How wide should resources be spread?

(g) What possibilities are there for international programmes?

(h) What is the policy for research training and development?

(i) What should be the funding ratio of fundamental to applied research?

It is the author's opinion that it is better for most countries to concentrate their resources on short- and medium-term goals. This is to enable international-quality standards to be achieved and an environmentally sustainable attitude to be developed. Both these are necessary for industries selling materials in Europe and the United States of America for instance. Some longer-term projects of specific interest should also be backed but based on national needs (e.g. renewable energy sources, etc.).

In the European Economic Community (EEC) for example, large-scale programmes are funded between industry and universities across national boundaries. The number of applications and the bureaucracy that has been created have started to bring many of these programmes into disrepute, especially amongst industry. The concept is right that a framework for new materials development is agreed (e.g. in the BRITE/EURAM (European Research on Advanced Materials) programme). However, even where partners meet all the criteria the chance of funding is less than 10% and the reasons for selection are not obvious to applicants. A more sustainable programme across Europe is one entitled EUREKA. In this instance a number of key areas are identified and companies/research centres are funded by their own Governments. Starting from a low base, large programmes can be created, contributing to a general advancement in a number of key industries. An example of this is the Biomedical Materials Programme, which has a budget of over $200 million. The contribution from individual Governments to the programme depends on each country's policy; in the United Kingdom it varies from 30-50% of full costs depending on the size of the company and how near the development is to the end market.

A similar set of questions to those on research can be asked of an educational policy. Apart from the approach and mix of subjects taught, a key issue is how teachers are kept abreast of a rapidly changing subject and how they can best adapt to the needs of a given country. That educationalists at the highest level should be involved in research is not open to debate. Attempts to teach materials without research has resulted in stagnation and a loss of motivation for both staff and students. Updating via industrial contacts and conferences is necessary. Key international publications must be freely available. The United Nations Educational, Scientific and Cultural Organization (UNESCO) could provide a useful function in distributing key reviews on various branches of new materials developments. A further experiment which is in progress between the EEC and the countries of Central and Eastern Europe is the TEMPUS scheme. The author's own department is, with two French institutions, involved in a large TEMPUS project (some $150,000 per annum) whereby staff from a Romanian technical university come for periods of a few weeks to several months to study teaching techniques and methods in the area of materials and manufacturing. At the time of this writing, the project is entering its second year; a number of research initiatives between the partners have been agreed upon.

Many countries have sent their best students overseas to undertake Ph.D. studies. These courses are valuable and provide good research training. Some countries now recognize that a better approach is to consider joint Ph.D.s. For example, the University of Nottingham and the University of Isfahan in Iran are now discussing plans for a four-year programme, with students spending two years in each location (generally this is on a one-year or six-month cycle). There is considerable advantage to both parties in that institutions are able to work closely together. It has been found that a single year abroad is generally not enough time to take advantage of any twinning arrangements.

Equally important is the need for continuing education and the education of user industries. A number of initiatives based on joint course development between industry and universities are in progress. An example is the in-house workshops of the European Powder Metallurgy Association on the application of PM to the automobile industry. Again the EEC has initiated awareness programmes on aluminium, steel and other non-ferrous products via their COMETT programme. The author is the chairman of the Materials Science and Technology Division of the COMETT initiative on aluminium. In this, some 20 plus universities and 6 trade confederations across Europe are involved in the development of training materials for designers and users of aluminium.

G. CONCLUSION

Development of a strategy for materials education and research is a complex undertaking which may require thorough analysis and understanding of the experience of other countries. Based on European examples of collaborative industry-government-university arrangements, one may describe programmes which could be utilized in the ESCWA region. But it is essential to take the special characteristics of the education system, the challenges confronted and the need of the economies concerned into consideration.

Discussion of Part One, Paper Four

Mr. Mohamed Kamel Mahmoud:

Q. I think the issue of synthesis and processing is not only crucial, it is one of the mechanisms by which, as identified yesterday, a number of economies have actually been able to dominate certain materials and certain technologies. It is not only crucial for the developing world to cope with processing of traditional materials; it is also essential to cope with more specific advanced materials. Many of these new processes that you are talking about seem to be emanating from university research. Is that correct? My question is: what is the role of local universities in developing these new technologies? What is the role of industry in developing and applying them and what is the linkage between the two? What role did your department play in developing new technologies and their application to industry and what is the relevance of that interrelation and the balance between the two in the development context? How do economies fare when they suffer from inadequate competence both in the development and application of new processing technologies *and* in the application of most traditional and new materials?

Mr. Jürgen Lexow:

Q. Product failure quiet often starts from the surface, so I would be interested to know about processes of coating surfaces. In addition to the normal material surface, there is the carbon coating of surfaces?

Ms. Wafa Abdel-Fattah:

Q. My question relates partly to Mr. Lexow's reaction, but the other part relates to coating: carbon coating, diamond coating on metal for biomedical applications. How is it done?

Mr. R.S. Ganapathy:

Q. My question is about the presentation of a process as a major variable in determining performance. We still make a presentation about educational systems. What I want to know are two things: first, to what extent did modelling figure in education, and can we train people to do modelling, or am I putting the question wrongly? This is the first question.

The second question is that there seems to be a considerable difference in emphasis on modelling as a way of improving performance which is a concern in advanced materials among different countries. For example, in analysis there was recently a study showing that the total of all materials research in development, about 25%, is actually going into modelling studies. This obviously is not the percentage in many other countries. I can say that in India it probably constitutes less than 1%. Very insignificant. I do not know what Japan represents. Perhaps Mr. Lexow can talk about Germany. What is the relative emphasis of modelling? There are alternative roots to improving performance and modelling certainly can improve process control and controlling the variables in the process. This is obviously an important way. So I would like to comment about the relative importance of modelling as far as improving performance.

Mr. Abdulla Babaqi:

Q. My question is on how you rely on *ab initio* calculations for modelling. From our experience in quantum mechanics and quantum chemistry, the approximate methods give better answers than *ab initio* calculations, and this may be inherent in the theory of quantum mechanics itself. The other thing is that, for the chemical engineer, empirical equations in heat transfer hold the answers to many questions for modelling heat transfer and material flow. The history of materials shows that many materials were discovered only accidentally, like teflon and many other chemicals. So because you have too many variables to monitor at the same time, you have a big problem. Clearly somebody will have to deal with this, it needs a great deal of cooperation, a great deal of work to do.

Mr. K. Hossain:

Q. My question probably has implications for materials in general. Processing is very expensive to develop. One question I think many developing countries would want to look for an answer to is the OSPRO process, for example. It is a very successful process, it was developed in the United Kingdom and then licensed in many countries. So should one be looking for licensing technology developed abroad, or should one develop some technologies in one's own country? I may have my own views, but I would like to listen to yours.

Mr. Zaidan Younes:

Q. I would like to know the meaning of thermal diffusivity and what the measuring unit is for this quantity? And what is its effect, if any, on the composite components?

Ans. Regarding building up competence and the link between universities and industry in processing, I think its fair to say that I do not know many processes that have actually been developed in the universities. You may get that impression, but from where I stand, we developed subsets of real processes. So we may develop, for instance, laser anemometry, which was actually developed at Harwell, which is a research institution, as a measurement technique, but then it has to be applied in a wider context. In fact, we face this problem in my own department: about how much do we invest in processes in our department? Actually, the answer is that we do not; we do not put in a big kit. It is an utter waste of time. I know I can say this because I have talked about it, but our friends in Romania, for example, have a laboratory full of rolling mills, a casting plant, injection moulders—everything you can name—and none of it does anything, because they cannot afford to run them and it really is a total waste of time. And what I think the university is good at is getting alongside industry and working with it in the development of the process, because although conceptually a simple process like sheet casting can be developed, actually, even to go up to 50 kilo melt capacities is far beyond what I can do. So what we have done is to set up one of these teaching-company schemes that I described yesterday to develop the process in the industry, and the sensing devices were developed in my own electronics department. We had one of our people on a teaching-company scheme working there full-time, and, as I said, as a result of that we actually got a product out the door. So I think it does depend on this industry-university linkage and schemes that make that linkage easy. I just do not believe that many processes start from scratch in universities, and if they do, they are probably highly suspect, so that is that.

You asked how you build up confidence. I think that you build up confidence by key people getting into key positions and taking this knowledge in. That links to a question asked by somebody else. How do we undertake modelling education and where does it fit in? Again, I think that is a big problem because you do need to be competent and experienced in a whole range of processes, things like fluid flow, mass flow and the rest of it, which is much more the chemical engineering side of things rather than the materials engineering side. And I am looking at this at the moment as to whether there are key areas of models that you can pick up, you really cannot get down to the basic computing. You must actually pick up these models and work with them. The main point I see is that you need to educate people as to the sensitivity of these models because models can do anything for you, as you know. As I said, they can predict all sorts of things.

Now turning to the *ab initio* against the approximate calculations argument which comes into that, I only highlighted that as a way of modelling which I think will have a future, but it is very far away at the moment. I totally agree with you that the other models are much more accurate. I would not suggest that the industry was involved in that; all I am saying is that I think in the next 10 to 15 years they will become more sophisticated, as you obviously know a great deal about it. The only variable that goes is the atomic number and that is it. But I am impressed by what I see because it does open up concepts, critical ideas which the rest of us can start using, and anything that opens up a window is good. But I would agree with you that the other ways are better at the moment. I think I said I would not put any money into that area; at this juncture it is just a highlight as to what was going on.

In relation to the thermal diffusivity and the data area, I will give you the full papers on that rather than go through them at the moment because it is rather complicated and I do not have the models in my mind, so I cannot really help you at the moment. But in turning now to coatings, I think surface engineering, which means everything from machine-prepared surfaces, implanted surfaces, painted surfaces and coated surfaces using PVD/CVD, are areas which the designer has now at his fingertips. The problem is the reliability of these coatings. Again, let us go back to the reliability of the processes and the models that we have for dealing with them. On the carbon coating front, it is incredibly sensitive to surface preparation and to gas concentrations and to temperatures and, in fact, the work we have done on the biomedical side has looked into this and, at the moment, we are looking at things like cell growth and toxicity levels for different processing conditions. It is very sensitive, and they are not actually models available for predicting at the moment, it does seem to be empirical at the moment.

PART TWO

Paper One

NEW AND ADVANCED MATERIALS TECHNOLOGY: CHALLENGES AND IMPLICATIONS FOR THE ESCWA COUNTRIES

A.O. Aribisala

Introduction

Media reports at home and abroad often carry stories of starvation and death through hunger and disease in developing countries. One is tempted to conclude that the developing world should devote more time to agricultural matters and primary health care rather than dissipating energy on development of advanced materials. However, since the economies of these countries are sustained mainly by the export of raw materials, they cannot ignore the threat posed by the replacement of traditional materials with new materials. Moreover, in the past the developing world stood by and watched while new technologies were developed and then struggled to use the technologies after they were obsolete. Next to the computer revolution, the materials revolution, characterized by the replacement of traditional materials, such as steel, copper, aluminium, glass, cotton, wool and paper, with organic synthetic materials, has had a greater impact on modern man than any other development. In view of this, it is timely that this forum reviews the issue of new materials.

Nigeria, like many developing countries, is a country with an indirect but substantial consumption of new and advanced materials. They form the components of a whole range of sophisticated products that are imported into the country. Also like many developing countries, Nigeria has just begun to appreciate the significance of new and advanced materials. Production and utilization of these materials is just beyond policy formulation and the laying of an effective foundation for a proper take-off in the production and use of new and advanced materials. For this reason, though the paper is based on the experience of Nigeria in the field of new materials, it deals mostly with the policy options for developing countries.

The term "material" covers a wide spectrum. In simple terms it denotes any physical matter used for things required by man. They are thus a key factor in the technological and economic development of all nations. Raw materials are the basis for engineering materials. New materials are often simply improved conventional materials.

With our basic definition settled, I would like to continue by stating that I agree with experts in material science in their summation that a combination of market pull and technological push has driven new materials forward at a faster rate than ever before in history. Market pull for high-efficiency and low-cost products implies a need for: (a) structural materials with lighter weight, greater stiffness, greater corrosion resistance and improved reliability; (b) enhanced and more effective functional materials (electrical, magnetic, optical, sensor, electro-magnetic, superconductive); and (c) biomedical new materials with better aesthetics, biocompactibility and biofunctionality.

The emergence of new and improved materials to meet these needs comes as a result of improved basic scientific understanding of the structure and control of these materials and their structure-property relations. The high-speed economic production of these materials using precise controls is a result of recent advances in instrumentation, equipment and data manipulation.

The immense economic gains resulting from the emergence of new materials in the last few decades have witnessed a corresponding, if not greater, boost in the world's technological advancement. The list of products is enormous and covers almost all facets of life. They have found usefulness in specific needs and requirements, for example:

(a) *Structural materials*: These include metals (special alloys, etc.), ceramics (synthetic diamonds, boron nitrite, etc.), polymers and polymer composites;

(b) *Functional materials*: These include semiconductors, photronics (fibre optics), photovoltaic materials (solar cells), sensors (thermocouple), electromechanical materials (inkjet printing head), superconductive materials, magnetic materials and amorphous alloys;

(c) *Civil engineering material*: These include, *inter alia*, concrete, cement and plaster;

(d) *Renewable materials*: These include wood and wood products (particle board, fibre board, etc.);

(e) *Biomedical materials*: These include prostheses, which have found use extensively in orthopaedics, cardiovascular systems (such as pacemakers, vascular grafts, etc.), hearing and intra-ocular devices and also as devices for the release of, for example, insulin.

To perform these demanding functions effectively, new materials of high standard and conforming with the desired level of aesthetics, biocompactibility and biofunctionality are continuously being produced.

How does the development of new materials affect demand for materials from the developing countries?

Table 1 shows that the developing countries account for a large percentage of world reserves of bauxite, copper, tin, cobalt, columbium, tantalum and phosphate. Vanadium, chromium, platinum and potash, on the other hand, are found in lesser quantities in these countries. While the emergence of fibre optics, for instance, may result in reduced demand for copper for electrical and electronics purposes, the replacement of silver with copper will result in increased demand (by volume). The replacement of chromium with cobalt will also entail a volumetric increase in demand for materials from the developing world. Many of the new materials find their bases in petrochemicals. A striking example is the substitution of various plastic composites for iron ore, which is dominated by the central economies and the Western industrial countries. Many of the materials being substituted have other applications. Chromium, for example, is one of nature's most versatile elements. It plays an important role in the production of armour plates, gun barrels, projectiles, heat-resistant machine parts, crankshafts, axles and gears. In the chemical industry, chromium helps to produce pigments and to process leather; in steel and special steel furnaces it is used for refractory purposes. Cobalt is an important alloying mineral for steel and also for production of super-alloys. The metal is also used by the electrical industry and by chemical industries in carbide production (cement) and as a pigment to colour glass. Tungsten finds various applications in the steel industry, in electrical applications (lamps and lighting) and in the chemical industry (dyeing).

The above discussion suggests that the volumetric requirement of raw materials from the developing world will not necessarily decrease in the near future. This observation, however, does not call for celebration. Table 2 shows the distribution of the world's consumption of metals. The developing world, and Africa in particular, consumes only a small percentage of metal. Thus, the consumption pattern of the rest of the world, especially the

Table 1. WORLD RESERVES OF MINERALS: REGIONAL DISTRIBUTION, 1985-1986

Commodity	World (thousands of tons)	Europe	North America	Latin America	Africa	Asia	Australia/ Oceania	Central econ. countries	Western industrial countries	Developing countries
Bauxite	2 103 400	5	0	28	33	9	21	4	26	70
Copper	377 000	1	22	33	18	5	4	17	26	57
Lead	86 500	12	35	6	6	3	17	21	67	12
Zinc	147 600	15	29	12	8	11	11	14	64	22
Tin	3 240	4	2	8	5	65	6	10	13	77
Iron	65 502 000	4	12	18	5	7	14	40	34	26
Chromite	1 057 700	2	"	1	81	3	0	13	80	7
Manganese	925 500	"	"	3	51	2	7	37	47	16
Cobalt	3 564	1	1	0	49	10	7	32	4	64
Molybdenum	5 307	..	60						26	..
Nickel	44 400	7	17						5	7
Columbium	4 125	..	3						78	2
Tantalum	23	..	8						7	16
Ilmenile (TiO^2)	177 800	19	22						1	21
Rutile (TiO^2)	19 750	..	1						1	21
Vanadium	7 165	0	3						0	56
Tungsten	2 630	5	24						3	1
Zirconium	36 100	1	20						2	19
Gold	40	0	10						6	62
Platinum Meals	31	..	1						..	80
Silver	244	3	26						29	4
Phosphate	85 433 000	6	59						22	69
(P^2O^2)	8 715 000	5	52						57	3
Potash (K^2O)	89 300	17	8						54	30
Fluorspar										

Source: ATAS Bulletin, Issue dated 5 May 1988.

Table 2. World metal consumption (refined) - regional distribution, 1985

Commodity	World (thousands of tons)	Europe	North America	Latin America	Africa	Asia	Australia/ Oceania	Central econ. countries	Western industrial countries	Developing countries
Aluminium	16 253	25	29	5	1	17	2	21	67	12
Copper	9 613	29	22	5	1	18	1	24	65	11
Lead	5 421	30	22	5	2	13	1	27	61	12
Zinc	6 492	26	17	6	2	19	2	28	57	15
Tin	213	26	19	5	1	21	1	27	61	12
Raw Steel (1983)	656 331	18	16	3	2	19	1	41	45	14
Nickel	787	28	20	2	1	21	1	27	67	6

Source: ATAS Bulletin Issues 5 May 1988.

Western industrialized nations, dictates to a large extent the prices of these metals. With the development of several alternatives (new materials), the situation worsens. Furthermore, if the developing countries are not involved in the development of new materials, they may find it difficult to acquire the technology when these materials are fully developed.

Processing and application of new materials in Nigeria

There is little or no industrial activity in the area of new materials production in Nigeria. Many of the efforts are confined to R&D organizations and universities.

One organization, Sheldan Technological Complex, has recently been established by the Federal Government of Nigeria. This Complex, under the presidency, will, when completed, address research and development on nuclear power and new materials technology.

The Raw Materials Research and Development Council (RMRDC), a government organization which funds raw-material research and development projects in R&D institutes and universities, has made efforts to document research efforts in the area of raw-material development. However, it is only recently that one of the Council's programmes became specifically dedicated to new-material development.

There are over 26 research and development institutes in Nigeria. The mandates of six of them make provision for materials development.

The Project Development Agency (PRODA) has, *inter alia*, the mandate to engage in research and development of machinery and equipment, particularly as they pertain to the use of steel, other metals, ceramics and glass for industrial and consumer gadgetry.

The Federal Institute for Industrial Research Oshodi (FIIRO) has successfully carried out research and development activities on the processing and application of locally occurring kaolin minerals. Some progress has also been recorded in the development of glazing materials.

The National Research Institute for Chemical Technology (NARICT) is charged with the responsibility of conducting research and development in the area of chemicals, polymers, leather and plastics.

The Nigerian Building and Road Research Institute (NBRRI) has developed alternative building materials from local raw materials. These include sun-dried, cement-stabilized and burnt clay blocks. Roofing sheets from coir fibre and cement have also been developed to replace conventional corrugated iron and aluminium sheets.

The Forestry Research Institute of Nigeria (FRIN) is mandated to carry out research and development activities on forest, wood and wood-based materials. Among the notable achievements of the institute are: wood-cement particle-board production; production of particle board from agricultural residues such as cotton stalk, maize stalk, elephant grass and rice stalk; production of ceiling board and roofing sheets from sawdust and other composites; and the processing of wood for use as wall and floor tiles.

The Rubber Research Institute of Nigeria (RRIN) has the mandate to develop the potential of the country in the production, processing and utilization of rubber. The Institute has made some achievements in the production and preservation of whole field natural rubber latex and latex-dipped goods. Other achievements include: development of latex bulking techniques, production of polymethyl methacrylate (PMMA), modified natural rubber, analysis of thermoplastic natural rubber (TPNR) and development of alkyd resins from local materials.

At least seven of the nation's universities and polytechnics are also engaged in some R&D activities in the field of materials development. The research projects include: production of polymer-matrix composite materials, acrylonitrile-menthyl-methacrylate copolymerization; acrylic acid-methyl methacrylate co-polymers; synthesis of polymer additives; utilization of local clays and whitings as fillers in plastics and rubber; development, production and analysis of latex dipped goods; and application of TPNR technology.

The above list shows that there few or no research efforts in the area of electronics materials and metal or in metal substitution. Furthermore, many of the research efforts in the areas highlighted have not been carried beyond the walls of the laboratories. Most of the vast raw materials available in the country have not been addressed by the researchers. For example, despite the ready availability (see table 3) of mica, silica, limestone, talc and petroleum products, there is no commercial production of reinforced polymer in the country. Therefore, RMRDC dedicated a programme specifically to new-material development. The assistance of UNIDO will be needed for this assignment, which will involve determination of priority activities in the area of new-material development and also the organizations with the relevant facilities.

Two classes of the current projects, if carried to the industrial level, will be of great benefit to the nation: these are the work on polymer-matrix reinforcement and that on ceramics. The work on polymer-matrix reinforcement should focus on those polymers that are produced by the two petrochemical plants in the country; the work on ceramics should be expanded to include engineering ceramics. It is gratifying to note here that an R&D centre for plastics is being proposed for one of our petrochemical production complexes.

International collaboration

The Government of Nigeria, through its various apparatuses, has established linkages with international organizations and Governments of other countries for the development of materials resources. For example, a memorandum of understanding, under which Nigeria's research centres will have access to facilities and experts from the Egyptian Central Metallurgical Research Institute (CMRDI), was signed in August 1991 during a visit by a Nigerian scientific and investment delegation (organized by RMRDC) to Egypt. Areas of interest include refractory bricks, production, clay beneficiation, talc processing, barite processing and ferro-manganese production.

Another memorandum of understanding signed by China and Nigeria in September 1991 covers manpower development, geological exploration and evaluation, mapping and mineral-laboratory technology. Major substances of interest include coal, phosphate, bauxite, gold, bentonite and barytes.

The Ajaokuta Steel Company Limited (ASCL) was created and charged with producing steel in quantity phases of 1.3, 2.6 and 5.2 million metric tonnes per annum based on the result of a study by a Soviet firm and Nigerian engineers and scientists.

In West Africa, the Government of Nigeria, through the Nigerian Mining Corporation, is participating to various degrees in the bauxite and uranium projects in Guinea, uranium and phosphate projects in the Niger, iron ore projects in Sierra Leone and cement projects in Benin.

Research and development activities

Materials research and development activities are confined essentially to the government-owned R&D organizations and the institutions of higher learning. The RMRDC is sponsoring selected areas of research on materials in some of these organizations. These include the development of ferro-alloys from local materials, production of ceramics, particle-board utilization and formulations for electrical insulators and resistors.

The Project Development Agency (PRODA) has made progress in the formulation of ceramic glazes and colours from local minerals and also in the production of porcelain insulators for low and medium vintages. The efforts of a private organization, Interlink Nigeria Limited, and of the Federal Institute of Industrial Research Oshodi (FIIRO) are also noteworthy. Among the successful projects of the National Research Institute for Chemical Technology (NARICT) are production of surfactant, tannin extracts and bating formulations from local materials. The Nigerian Building and Road Research Institute (NBRRI) has developed improved alternative building materials such as sun-dried, cement-stabilized and burnt clay blocks; roofing sheets from coir fibre and cement; and pozzolana and lime from local materials.

Table 3. RESERVES OF MINERAL RAW MATERIALS IN NIGERIA

Asbestos	Not yet known
Barytes	Over 700,000
Bauxite	Small Not known
Clay	Over 50,000,000
Kaoulin	Over 70,000,000
Fireclay (Refractory)	Large
Diatomite	Small
Dolomite	Large (about 80,000,000)
Feldspar	Small
Mica	Small
Flourspar	Small
Gypsum	Large (not yet known)
Kyanite	Not yet known
Limestone	Large (up to 800,000,000)
Phosphate	Large
Silica sand	Very large
Brine	Not yet known
Soda Ash	Small (not yet known)
Talc	Not yet known
Tin Ore	Large
Iron Ore	Large (2.0 to 3.0 billion)
Coal	Large (Over 500 million)
Manganese	Trace amount
Vanadium	Trace amount
Ilmenite	Small
Nickel	Trace amount
Chromite	Trace amount
Niobium	Trace amount
Columbite	Large
Molybdenum	Trace amount
Zircon	Trace amount
Wolfram	Trace amount
Tungsten	Trace amount
Titanium	Trace amount
Tantalum	Small Amount
Monazite	Trace
Silimanite	Trace amount
Magnesite	Trace amount
Marble and Dolomite	Large (Over 100 million tonnes)
Galena	Large
Gem Stones	Large

Source: RMRDC's MTF (Report)

Wood-cement particle board, ceiling board and roofing sheets are among the projects completed by the Forest Research Institute of Nigeria (FIN), and the Rubber Research Institute of Nigeria (RRIN) has made some achievements in the production of rubber and latex-dipped goods.

There are a number of organizations currently working on the design and development of a Nigerian vehicle. These include ADDIS Engineering, Ahmadu Bello University (ABU), Kwara State Polytechnic, Project Development Agency (PRODA), and Anambra State University of Technology (ASUTECH). These designs are based on traditional materials.

The low priority given to the electrical and electronics sector by the Government of Nigeria is indicated by the non-existence of a research and development organization dedicated to this field. The universities and polytechnics are, however, engaged in research, much of which they have not been able to translate into industrial activities. Very little of this research is directed at component manufacture or at the development of electrical/electronics materials. The major reason for this is the limited facilities available and the low level of industrial activities in the sector. One of the universities, Obafemi Awolowo University, however, boasts of some facilities around which a modern electrical/electronics materials laboratory could be built.

The chemical engineering development facilities of the University of Lagos, the Rubber Research Institute of Nigeria and the Rubber/Polymer Technology Department of Auchi Polytechnic can easily form the nucleus for the establishment of a centre for the development of engineering plastics. Similarly, PRODA and FIIRO can expand their activities to address engineering ceramics, and the National Metallurgical Institute can collaborate with metallurgical engineering units at the University of Lagos and Ahmadu Bello University to work on metals and their alloys.

Towards a materials policy for Nigerian new materials

The discussions in the previous sections show that the material potential of the country has not been fully exploited. The Federal Government of Nigeria needs to synthesize all the policy statements and decrees into a national policy on materials, bearing in mind new developments in the world. The formulation of such a policy will require the analysis of the need for and potential of materials in relation to industry, economy and trade.

An important factor is the trend in materials substitution and development of new technologies for materials processing which has resulted in the change in the consumption pattern of traditional materials worldwide. For example, the OECD consumption of metals such as steel, aluminium, copper, lead, zinc and nickel, which rose steadily between 1950 and 1970 has remained at the same level or has even decreased since the 1970s despite the increased production of goods. This is a clear indication that these metals are being substituted by new materials or that the material contents of products are being reduced.

Ceramic components are now in commercial use in a variety of engines, mainly in Japan and to a lesser extent in the United States and Germany. The advantage of ceramics is essentially its ability to withstand high temperatures, which eliminates the requirements for water or air cooling in diesel engines. It has been estimated that 10,000 ceramic turbochargers per month are installed in cars produced in Japan. Other ceramic engine components in use include glow plugs, pre-combustion chambers, rocker arm pads, and exhaust port liners. Some other ceramic components under evaluation include valves, valve springs, retainers, pushrod tips, fuel injector components, valve lifters and valve seats. Ceramics also find applications in heat exchangers and machine tool bearings (4)[1].

Plastics and advanced polymer composites probably pose more immediate threats to metals than ceramics in other industries. The advantage of plastic is that it can be tailored to the precise requirements at various stages which include polymerization compounding or processing. Plastics are combined with non-plastics to obtain desired end products. Plastics and their composites have had great success replacing metal in the aerospace industry and in the paper market.

It is projected that the competition between metal and advanced plastics will accentuate. For example, by the year 2000, polymer composites may account for 65% (as compared to 3%) of passenger aircraft, replacing aluminium in the main. Airframe weight may consist of only 20% aluminium as compared to 80% today. There is also a threat to copper by optic fibres. The threat is not confined to metals. Part of the research efforts is now aimed at reducing dependence on specific strategic and critical minerals such as cobalt, chromium, manganese and tungsten in military and high-technology applications (3).

It has been argued, however, that it is naïve to believe that new materials, alloys and composites will rapidly replace traditional materials in conventional products (5). Because of advances in construction techniques and design, less steel is used in buildings today than in the past to achieve the same superior structural characteristics; the application of high-resistant steel in the automobile industry, for example, has advanced more rapidly than that of plastics.

Ceramic-fabrication technology is complex and sensitive to small variations in procedure. Great attention has to be paid to the detection and elimination of flaws because this determines the strength and the degree of reliability. In order to eliminate the need for machining, which is considered the most expensive step in the sequence of fabrication, powders are formed into shapes that are capable of providing components of close to final dimensions after treatment. Furthermore, monolithic ceramic components are of inherently low toughness compared with metals. Thus, fibres or whiskers are incorporated in a ceramic matrix to improve toughness.

As stated earlier, plastics are seldom employed without being combined with non-plastics. Materials such as glass fibre, glass beads, talc, calcium carbonate and mica are added to polypropylene to improve rigidity, strength, impact toughness, dimensional stability, heat resistance, chemical resistance, flow and warpage control, hardness, deflection temperature and colourability.

The United States Office of Technology Assessment (OTA) concluded not long ago that advanced materials would not significantly affect the demand for aluminium and steel in

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[1] For the list of references, see page 322.

the near future because of the suitability of these materials for their current applications and ease of manufacture at low cost. One school of thought believes (3) that over the next 5-10 years existing metals are virtually assured of a market, which will increasingly comprise composites produced with advanced technologies to meet specific markets in developed countries. It is envisaged that increasing costs in developed countries will lead to gradual relocation of processing capacity to the third world and developed countries rich in resources and energy; transnational corporations will move out of commodity-metal production and concentrate on fabricating high value added metal products near the markets within industrialized nations.

Table 4 reflects the state of development of mineral processing technology in Nigeria. It is apparent that Nigeria has yet to move away from mineral beneficiation into the area of translating these materials into new materials. There arises a question: should Nigeria jump this stage of mineral beneficiation and channel her material, financial and human resources into the utilization of new materials developed by the industrialized world? In support of this approach is the observation that the countries which develop domestic capabilities in particular industries are not necessarily the ones in which diffusion and assimilation are most efficient. In the case of microelectronics, for example, the Japanese consumer-electronics makers have incorporated microelectronics in the most competitive fashion in everything from watches to cameras despite the fact that the United States dominates the market for chips (2).

It is difficult for Nigeria to adopt this approach because the infrastructural requirement and the manpower necessary to utilize the new materials competitively are lacking.

The other approach is to ignore the new materials and concentrate on the beneficiation and optimal use of the traditional materials for local production of goods. Again, a problem arises. Much of the equipment needed for the processing of raw materials are imported. With the advanced countries moving away from traditional technologies, this equipment will become obsolete, unless the country can develop a capability for equipment fabrication and design.

As observed earlier, an audit of equipment design and fabrication capability in Nigeria by RMRDC revealed that there are gaps in the system. These gaps include a limited number of fabricators with good knowledge of process and equipment design and materials selection; limited facilities such as heat-treatment shops, foundries and metal-working shops; and fabrication materials and other infrastructural supports. All these factors are being addressed by the Government and by the private sector, but it will take a year or two before the full impact of these efforts is felt.

Arguments have been put forward against the idea of promoting capital-goods production in developing countries in the age of microelectronics. The question, however, has been asked: which countries are more likely to succeed in the 1990s?(3) Those with an established engineering capital goods sector and with experience in the use of new technologies or those with neither? The answer is obvious. It is in this light that the Government of Nigeria is determined to continue its developmental projects in the iron and steel industry, lead/zinc smelting plants, aluminium smelting plants, mineral-beneficiating plants and petrochemical complexes.

Table 4. CURRENT STATE OF MATERIALS PRODUCTION/PROCESSING TECHNOLOGY IN NIGERIA

	Plant	Current State of Technology
1.	Kaolin Processing Plant	Small/Medium Scale Plant (5,000 tonnes/annum) exist
2.	Barite Processing Plant	Medium Scale Plants (120,000 tonnes/annum) exist
3.	Lime Production Plant	Small Medium Scale Plants exist
4.	Dolomite refractory bricks production plant	Plant not on ground
5.	Plant for the production of silica refractory products	Plant on ground not operational
6.	Plant for the production of fire clay products.	Plant not on ground RMRDC has initiated a catalytic project in collaboration with State Government
7.	Talc beneficiating plant project	Plant not on ground RMRDC has initiated a catalytic project
8.	Plant for formed coke	Plant not on ground
9.	Granite polishing/decorating plant.	Medium Scale Plants on ground RMRDC has initiated a catalytic project
10.	Gemstone cutting and polishing machine	A plant on ground RMRDC has initiated a catalytic project
11.	Iron ore beneficiating	Pilot Plant on ground (Iron ore plant being stock piled)
12.	Cement Production Plant	Large Scale Plants on ground
13.	Gypsum Processing Plant	Small/Medium Scale Plants on ground
14.	Trona (Soda Ash)	Plant not on ground (RMRDC processing plant Catalytic plant in progress)
15.	Diatomite beneficiating plant	Plant not on ground
16.	Phosphate beneficiating plant	Plant not on ground (RMRDC Catalytic plant in progress)
17.	Cassiterite beneficiating	Small/Medium Scale Plants on ground

The country needs to address, however, the issue of new materials and new technologies in preparation for the time when its industrial base and its engineering and scientific skill and sophistication will have increased sufficiently to apply advanced manufacturing techniques. Furthermore, the marketing strategies of the transnational companies may entail a global push in the use of advanced materials.

Manpower development

A crucial factor in technology acquisition and adaptation is the availability of required manpower. It has been observed that one of the factors militating against new materials is the preference of many metallurgists for materials with which they have been trained. Thus, it is important that the curricula in the universities and polytechnics be redefined to address the changing technologies worldwide. It has been observed that no amount of technological forecasting can predict how the scientific and technological process will combine to meet the needs of the society. Thus, there is a need to develop manpower in all disciplines (metallurgy, chemical engineering, material science and technology, etc.).

University/R&D organizations/industry interaction

The R&D organizations which attempt to focus more on applied research are constrained by limited funds. Many of the research projects have been discontinued because they have not been based on the needs of the society. There is a need for these organizations to collaborate with the industry, which is capable of assessing the possibilities and the scientific limitations of technological manufacturing operations.

The Raw Materials Research and Development Council brings together industrialists, academicians and experts from R&D organizations periodically to determine or re-evaluate research priorities. In order to determine priority areas for R&D, it may be necessary to consider the areas of relative advantage. For example, Nigeria has a deposit, albeit in trace amounts, of molybdenum, which has been suggested as a corrosion inhibitor (in its elemental form or as an alloy) for materials used in sulfiding environments. This may form a lead for research activities. However, the trend in new materials development is to "create" materials based on the needs of the society.

Apart from helping the universities and R&D organizations define a research agenda, the industries will define the curricula, educate materials scientists and engineers and familiarize the students with operational conditions in the industry.

Infrastructure

The Federal Government has taken a major step towards the development of materials by establishing the Raw Materials Research and Development Council and the Sheldan Technical Complex. The Complex will establish its infrastructural facilities taking full cognizance of trends in the world of materials development. While attention will also be paid to conventional workshops and others, provision will be made for vacuum melting and casting techniques, directional solidification techniques, powder metallurgy and so on.

The rate of development of new materials and new technologies creates the need for more efficient acquisition, storage, processing and dissemination of information in order to:

(a) Avoid a situation where the nation is saddled with obsolete technologies;

(b) Help direct research efforts, manpower training, funds allocation, market target and infrastructural development.

Financing

Financing research and development in the area of new materials development is unlikely to attract funds from the private sector at present. This is because the profit-oriented industries cannot be convinced of the profitability of such ventures in the near future. Thus, funding research and development in this area is confined to the Government. The proposed interaction of universities, R&D organizations and industry discussed earlier may change the attitude of the industry. The R&D institutes could also generate funds from services provided to the industry and the society at large. It is noteworthy, however, that the Raw Materials Research and Development Council is funded by a surcharge on import duties.

The National Science and Technology Funds have been set up specifically to address the financial requirements of research and development in the country. There is a need to set aside a sizeable proportion of this fund for materials development. The conventional annual disbursement of funds may not be the best option since new materials development is a long-term project.

The Government may want to examine granting soft loans for the establishment of industries that translate R&D results on new materials into commercial ventures. Tax incentives for long-term capital savings and patent protection for new developments could be added incentives.

International collaboration

A cue should be taken from developed countries which, despite superior facilities and manpower, collaborate for technological advancement. An example is the Versailles Project on Advanced Materials and Standards (VAMAS) involving Canada, France, Germany, Italy, Japan, the United Kingdom, the United States and the Commission of the European Communities. The activities in 13 technical areas include: (a) establishment of priorities; (b) consultation and collaboration; and (c) comparison of specific measurements in a number of government and commercial laboratories.

Developing countries should work together to define technical areas and activities along lines similar to those mentioned above. The technical areas should be based on the common needs of the developing countries and the areas of comparative advantage.

The role of UNIDO in promoting international cooperation and institutional capability building in the area of materials science and technology is acknowledged. There is, however, a need to publicize the facilities available under the auspices of UNIDO. For example, the UNIDO Industrial Technological Information Bank is expected to play an important role in developing and disseminating data bases on the design, production and use of new materials and associated processing paths. It is also important to publicize project-funding opportunities offered by UNIDO.

The role of manpower development and market outlet in the development of materials having been acknowledged, there is a need to involve UNESCO and UNCTAD together with the regional commissions in the process of formulating and implementing materials policy in developing countries.

Policy stability

It has been observed that past policies in Nigeria were characterized by frequent changes or instability as a result of changes in Government or in the personalities of the operators of the system. When Governments changed and different operators emerged, there was always the tendency for the value system that had underlain previous policies to change. While modifications or revisions in policies may be induced by unforeseen circumstances, external factors or unavoidable error, stability and continuity are of crucial importance to the attainment of the goals and objectives of the policies. It is essential to monitor and evaluate policies continuously to correct deviations from established guidelines as soon as they are discovered.

Conclusion

1. The total volume of raw materials obtained from developing countries as a group may not necessarily decrease significantly in the near future. However, the wider range of choices being developed enables the buyers rather than the suppliers to control prices.

2. The current research and development activities have not fully exploited the vast raw materials available in the country for development of new materials. Thus, there is a need to formulate a definite programme on materials development.

3. Developing new materials may be time-consuming and expensive. Thus, many of the research efforts may lie idle unless special efforts are made to commercialize them. The Government needs to encourage long-term capital investment in materials by the potential users. This includes the provision of tax incentives for long-term capital savings and patent protection for new innovations.

4. Collaboration among universities, research organizations, industries and the government should be facilitated. This may take the form of provision of special grants by Government or by industries for use in R&D organizations or universities. The results of the research activities should be made readily available to the industry.

5. Curricula in the universities and polytechnics of developing countries should also be re-examined to ensure that materials process technology is adequately addressed. Two areas already identified as being viable technologically and economically are the production of polymer matrix composite materials and the production of engineering ceramics. Three projects are therefore proposed for immediate consideration.

In order to coordinate the various materials development activities in the developing countries, it is proposed that each country select a centre for materials development. One of these centres should be designated as the secretariat to serve as a meeting point for exchange of research ideas and results. The establishment of these centres should be done by the Government of each country in close collaboration with UNIDO.

REFERENCES

1. E.D. Hondros, ATAS Bulletin, page 3, Issue dated 5 May 1988.
2. John M. Marcum, ATAS Bulletin, page 128, Issue dated 5 May 1988.
3. Lakis Kaounides, New Technologies and Global Industrialisation, page 165 (1989).
4. Loius J. Sousa, Charles A. Sorrell and others. *Advanced Materials: Outlook and Information Requirements* (1989).
5. Jose E. Cassiolato, ATAS Bulletin, page 137, Issue dated 5 May 1988.

Discussion of Part Two, Paper One

Q. How far have you gone in upgrading your kaolin deposits and are they ready for export?

Mr. Ali Dajani:

Q. My question is brief. Your talk is very clear, but really I wonder after so many years of independence and such an abundance of raw materials that you do not industrialize the raw materials that are available to you. I mean, in our area, we buy peanut oil, and you do not have peanut oil; we find Nescafé in Europe and in our area, and you have the coffee and you have all these things. I wonder what is the impediment in your country? Is it the infrastructure? Is it education? Or is it that the technological institutes are not there?

Ans. To answer the first question, as I mentioned, we have proven estimates of 70 million tonnes of kaolin and for the past five years most of the kaolin plants we had on the ground were put in place by some Indian companies for the purposes of preparing this raw material for export. Then, in the past three years, we decided, because we have a problem with the devaluation of our currency which, in fact, made importation of turnkey machinery for the processing of this mineral impossible. So we put a multidisciplinary team together that has now come up with a plant which can process 5,000 tonnes of kaolin per annum and we put up the catalytic model plant for this kaolin plant in the northern part of the country where they have a pure grade of kaolin. The model took 18 months to put in place. What we then did was to have a guided tour of this model factory for industries. We found out that since that time we have at least five similar projects being replicated in different parts of the country. So as far as the kaolin is concerned, it is used in large quantities by the paint industry. We found out that we still need more of these kaolin beneficiation plants and, in fact, some of them are going further to produce calcium carbonate for export, so we believe that for now we are still importing kaolin because the installed capacities are not enough to satisfy the industries in the country. But our projection is that in another five to ten years we will be able to meet our requirements and satisfy exports.

As far as industrialization is concerned, we had a setback because of the oil boom. As you know, if we trace the issue of industrialization in Nigeria, we find that industrialization was limited to first-stage cleaning of certain agricultural commodities to feed industries in the United Kingdom. So groundnut, cotton, cocoa were not processed there. They were simply graded and exported. It took so much for national companies to start off the real development of these industries, but just as we were about to take these steps, we had the oil boom and so less emphasis on industrialization and more on importing, because we could afford importation. But then with the oil gloom, we had to reassess our priorities. I would like to say that we have so many industries in place but compared with the population of 58.5 million and the land mass of the country, we still have to do more. But we have many agro-light industries in that area and we have made a great deal of progress: we are processing our groundnut oil, we are processing cotton, and we have done very well in textiles. We are exporting textiles, and I think we are, in fact, doing best in the whole region in terms of textiles. We are exporting furniture and other products, and I believe that in the area of petrochemicals, too, we have made a great deal of progress. We produce carbon black; we produce benzene; we produce some other types of petrochemicals. But the issue is that, in a country with such a large population, it seems like we are doing nothing because of the domestic demand. In fact, apart from Nigeria, we are servicing the market up to Abidjan and Ghana. Many of the surrounding countries have shut down their refineries because they are relying on our oils which we are producing at subsidized rates. So we are subsidizing many industries within the ECA region. We have established a cement industry in Bene; we have established beneficiation plants in Liberia. So we have joint ventures scattered all over Africa. So I think now that we know that we have to diversify an industrial base. We are putting a great deal of effort and we have also been on a huge drive to invite foreigners who might invest in the first stage of processing of some of these minerals.

Paper Two

MATERIALS TECHNOLOGY IN INDIA: REVIEW AND PROSPECTS

R.S. Ganapathy
National Materials Policy Project

Introduction

Materials have always played an important role in the development of civilizations and in meeting the economic, social and cultural needs of the people. Material science and technology is instrumental in developing new materials and in improving the properties and performance of materials. In the last couple of decades the trend has been towards a decline in the material intensity, through improvement in the performance of materials. With the advancement of science and technology, new materials are developed to substitute for many of the conventional materials used in various sectors. In India, this trend is slow but it is gathering momentum, as concern about environmental degradation, energy intensity, resource depletion, substitution and competitiveness and import are increasing. Considering the importance of materials in the future of our country, the field of materials should get high priority in the programme for economic development.

Indian raw material reserves for many of the key materials offer good potential to produce them in economic quantities. The ore quality in some cases is poor, but pretreatment technologies available can overcome this problem. The technology required to produce these materials and downstream products within the country is growing very slowly in spite of fairly well established infrastructural facilities and trained manpower. Repeated import of technology and materials without further improvement and innovation still continue.

In the light of the above, it is important to take stock of the material technology status with reference to some key materials so that a programme can be chalked out to make India more competitive in the world of materials. Considering the fragmented R&D efforts and lack of coordination among institutions, poor rate of technology transfer from R&D laboratories to industry, lack of targeted, use-driven funding mechanisms and low level of information/knowledge dissemination, it is important to develop an institutional framework with an active participation of various stakeholders. Also, such a framework is needed to evolve priority areas, based on a shared understanding of the stakeholders. This review makes an assessment of materials technology in India in key areas of economic importance, identifies gaps and develops action plans in relation to national goals. It is based on technical reports of the Scientific Advisory Council to the Prime Minister, especially commissioned papers and the research outcome of the National Materials Policy Project, a major inter-institutional effort to develop long-term policy options for the development, production and use of materials, which is currently under way.

A. BACKGROUND

India has considerable resources, but these resources are not being utilized optimally. In terms of manpower too, India is endowed with abundant skilled and unskilled manpower, which compared to many developed countries, is cost-effective. In spite of all these advantages we still supply raw materials and manpower to developed countries and continue to import technology and finished goods for our development from other countries. Materials play a vital role in the development of any country. Inefficient utilization of our resources has been recognized in the recent past and now efforts are under way to increase the utilization of our resources more efficiently by value additions and technological upgrading. Towards this end, an assessment of the technology status with respect to some key materials is very important.

Indian raw material resources have good potential to meet the domestic demand and to a great extent even export needs. There are some quality problems in the case of some materials but these are marginal which can be tackled with better pretreatment methods for which technology is available. In the case of manufacturing and processing technology, we still rely heavily on imports. Our success in assimilating these technologies still remains inadequate. There are good infrastructural facilities and scientific manpower in R&D labs, and many of them have developed indigenous technologies but the extent of commercialization or development of application-oriented technologies have been poor. Looking at our facilities and infrastructure, there is enough evidence to show that a consortium approach (with complementarity and synergy) can sustain commercial innovation. The integrated guided missiles programme and other high-tech programmes can be cited as examples of coordinated approaches.

In India, there are several material R&D centres with fragmented efforts and poor sharing of knowledge/information. This has resulted in duplication of efforts and inability to build on cumulatively. Similarly, resource allocation for materials technology development is also highly skewed and distorted. Such distortions have resulted in wastage and scarcity of funds.

The net result of the above-mentioned characteristics of the material R&D scene is excessive reliance on imports of technology and high quality materials. A concerted effort can make India more competitive. Presently, we tend to export raw materials and import value added products. The recent liberalization policies provide ample opportunities to improve our technology but we have to develop our capabilities to assimilate technologies and modify them to suit our needs. Materials have been targeted as a priority area for economic growth during the 1990s and beyond by major economic powers. India too can make significant progress in materials technology led industrial development, provided we can use technology effectively. The following sections outline how this can be done. For a more comprehensive strategy, the reports of the National Materials Policy Project may be consulted.

B. METALS AND ALLOYS

Though India has a rich tradition in the production of materials, Indian metallurgy witnessed real changes only in the post-independence era. Plants to produce steel, aluminium, copper, zinc, etc., were set up during this period. Most of these metals have good resource potential in India (SAC: Report to PM, vol. II, 1990).[1] Owing to low resource utilization to produce final products, some of these raw-materials are being exported. The quality of some of the metals produced in India is not suitable for high-tech applications. Hence, many of the special quality metals are being imported in spite of the country's rich domestic raw material reserves. The main problem is lack of technology, resulting in production of poor quality products and high cost of production. India has built up extensive facilities for research and development in metals over the last 75 years. Some of these centres have made remarkable scientific progress but are not effective owing to poor commercialization of technologies. Technology development, with a strong understanding of the correlation between structure and properties, to evolve new materials and for enhancing the properties of conventional materials

[1] For the list of references, see page 348 *f.*

to meet specific requirements can yield better results. While scientific knowledge gets disseminated rapidly across geographical barriers, the flow of technologies across space is not very smooth. This is partly due to the important role that technologies play in determining the richness of a nation (SAC: Report to PM, vol. I, 1990).

Producers also complain about uncertainty in the supply of raw materials. Improvement in mining technology and pretreatment of raw materials is required to improve the quality of raw materials. In spite of several other materials substituting for iron and steel, the dominant role it plays in the core sectors (construction, transport, capital goods, etc.) still continues. World over, the trend is to reduce the material intensity of steel by improving the quality of steel. In India too this trend is just beginning. Especially with the strong threat of substitution by other materials such as polymers and aluminium alloys, steel producers are making efforts to improve the quality of steel to achieve weight reduction with superior properties. The per capita consumption of steel in India is 19 kg., one of the lowest in the world (Ranganathan, 1992). In future, the supply-led demand pattern is likely to change. The demand for steel by 2001 is estimated to be around 38.1 million tonnes (SAIL, 1991). As of 1990-1991, 91% of the production of steel was from large producers such as SAIL and TISCO.

Technology

Most of the integrated steel plants operate with outdated technology. There is clearly a need for modernization. Though the quality of steel in India has improved, we still continue to import high quality steel required for many sectors. TIFAC studies on modernization of the steel industry provide valuable directions in this regard (NMPP, 1992). There is need to upgrade technology for pre-treatment of raw-materials and processes such as continuous casting, ladle refining, electromagnetic separation, etc. The technology adopted by mini steel plants is not adequate to produce high quality steel. Along with modernization of the existing large-scale steel plants, it is necessary to upgrade the technology suited for mini steel plants. Pollution created by this industry is also quite high. The wastes created during steel production offer good recycling potential. Adoption of recovery techniques such as the tetronics process would help in the recovery of metals such as zinc, lead and cadmium from electric furnace flue dust.

R&D infrastructure in India mainly exists in large scale units of SAIL and TISCO. The role of mini steel plants in R&D efforts in future will have to be strengthened by involving them through a collaborative programme to facilitate smooth transfer of technology from R&D laboratories to industry.

Human resources development for industry personnel is mainly undertaken by in-house training centres of large producers. There are courses offered by academic institutions too. Facilities in industry to train people for their requirements are adequate in SAIL and TISCO. However, for instrumentation control systems, some facilities to train people will be required. In the case of mini steel plants, training facilities are practically non-existent.

Action plan

(a) Emphasis on technology development for the iron and steel sector should be for production of special grade steels and value added items, pre-treatment of raw materials, automation, energy conservation and new processes (such as continuous casting, ladle refining, electromagnetic separation), waste recovery and pollution abatement, modelling of processes, etc. Cost reduction and product/process innovation should be the primary objectives of technology development.

(b) Technologies such as ladle-refining and electro-magnetic separation can be imported and adapted.

(c) Funding for R&D should come mainly from industry and users to address market preferences.

(d) Greater involvement of mini steel plants needs to be ensured in cooperative R&D activities and technology transfer for modernization and product innovation. Training facilities required for this purpose will have to be developed through industry associations (e.g. CII).

(e) An information centre to disseminate information regarding technologies, new products, market trends, etc., is needed. This will be particularly useful for the small and medium scale sector.

Aluminium

Indian bauxite (the basic raw material for aluminium) reserves can sustain production of aluminium (at 1989-1990 level of production) for about 250 years. Most of the reserves are located in the east coast of the country. Power consumption to produce aluminium is comparatively high (16,500 KWH per tonne). Erratic power supply affects the capacity utilization and results in large-scale waste of heat. Consequently, the production cost is high.

The demand for aluminium is not clearly estimated in India. The consumption was always supply driven. There was always a sudden increase in consumption of aluminium whenever a new plant started production (Ganapathy and Padmanabhan, 1991a). With the commissioning of NALCO, the supply position improved and India has started exporting aluminium. However, aluminium consumption is increasing and very shortly there may be supply constraints.

India still imports special quality aluminium required for sectors such as electronics.

Technology

The aluminium industry in India is more than four decades old. The technology adopted to produce aluminium in India is imported. Even the latest plant, NALCO, set up in 1987 uses imported technology. The design and engineering capability to set up an aluminium plant independently is lacking in India. Earlier terms of technology transfer did not allow horizontal transfer of technology. As the industry is oligopolistic, its technology, raw materials production and fabrication are all controlled by a few transnational companies. In spite of the fact that the industry is four decades old, further upgrading of the processes has not taken place in India, whereas in developed countries improvements, especially reduction of energy consumption, are common. The technology adopted by NALCO has a power consumption of 13,700 KWH per tonne, whereas the other, older plants consume about 16,500 KWH. Production of secondary aluminium consumes only 5% of the power required to produce primary aluminium. At present the production of secondary aluminium in India is less than 10%. Because aluminium is a light metal, its use in the transport sector results in fuel savings. In India the maximum aluminium used in cars is by Maruti Udyog Ltd. (20 kg. per vehicle), but compared with the world average (60 kg. per vehicle), this is low. The technology required to produce high purity aluminium foil required for the electronics industry is not available in India. Almost the entire quantity of foil required for this industry is imported. The environmental problems created by aluminium industry are mainly through the disposal of red mud. Recovery of valuable materials such as vandium, gallium and titanium from red mud is possible. To reclaim the land used for disposal of red mud, HINDALCO has identified some species of plants which can survive on this material and has initiated a land reclamation programme.

Action plan

(a) The products that should get maximum attention for technology development are aluminium alloys, especially those required for the transport sector and aluminium foil required for the electronics industry. Alloys for the transport sector should be developed in collaboration with vehicle manufacturers. To encourage the use of aluminium alloys in the transport sector, norms can be evolved collaboratively. In the case of foils, the technology may have to be imported and assimilated to suit our requirements.

(b) Processes that should get attention are rapid solidification, powder metallurgy, superplastic forming, energy efficiency and testing and evaluation techniques. This will have to be done in collaboration with aerospace and defence sector laboratories. Squeeze casting techniques for making automobile components such as pistons and wheel hubs have to be developed through collaborative efforts.

(c) Recovering valuable materials such as gallium, vanadium and titanium from red mud is vital. Similarly, it is necessary to develop plant species that can grow in red mud disposal grounds.

(d) In-house training centres provide most of the training required. Facilities for computerized process control systems and instrumentation are weak. This will have to be taken up by industry associations or within firms. The activities of the present Aluminium Promotion Council will have to be intensified. There is a need for establishing an Aluminium Information Centre. The newly created Jawaharlal Nehru Aluminium Design and Development Centre can play an important role in application technology and training.

Copper

Indian copper reserves are estimated to be around 8.3 million tonnes, accounting for 8.5% of world reserves. The ore content is very low - 1.27%. In India there is only one producer, Hindustan Copper Ltd. (HCL), a public sector unit, with an installed capacity of 47,000 tonnes per year. Current (1990-1991) availability of copper is about 64,558 tonnes. It is estimated that by the year 2000 the domestic demand will be around 250,000 tonnes against a supply of 120,000 tonnes. In electrical wires and conductors, substitution of aluminium is taking place. Other materials replacing copper are stainless steel and titanium in condensers and heat transfer applications and optical fibres in telecommunications. Indigenously produced copper is expensive owing to the high cost of input materials including power and fuel, frequent disruptions in power supply, etc. The advantage of lower labour cost in India is offset by excess labour and poor productivity.

Technology

The basic technology employed in copper production is not different from traditional technology except that modern equipment and machinery permit mass production and better control. The technology used at present integrates roasting, smelting and conversion to produce directly electro-refined copper (Indian Copper Development Centre, 1991). For downstream products, wire drawing, rolling, extrusion, electro forming, powder metallurgy, etc., are used.

R&D in copper is carried out mainly in the in-house R&D centres of the copper industries and the national laboratories (e.g. DMRL, NML), technical institutes and universities. At HCL, R&D efforts are directed towards mining, beneficiation, hydro-metallurgical extraction, smelting, refining and by-product recovery. The newly established Non-ferrous Technology Development Centre at Hyderabad is undertaking significant work in copper. Facilities for training on the job personnel are confined to HCL. Technical consultancy services are mostly obtained from foreign companies through MECON and EIL who undertake the responsibility of installation and execution.

Action plan

(a) A detailed study is required to understand the changing sectoral pattern of copper consumption and substitution, to focus technology development on high priority areas.

(b) Conservation and substitution of copper in key sectors are needed.

(c) Labour productivity in the copper industry will have to be increased, by new technology.

(d) Since the ore content in Indian raw material is low, there is a need to develop technology to extract copper more efficiently.

Titanium

India possesses about 25% of world titanium reserves. About 146 million tonnes of ilmenite and 9 million tonnes of rutile, major sources of titanium, are contained in the beach sands of India (TIFAC, 1991). Titanium pigment production in India is about 20,000 tonnes but the demand is estimated to be around 35,000 tonnes. Titanium sponge is not produced in India. There is only one producer of titanium mill products with a capacity of 65-70 tonnes. Titanium tubes are also not manufactured in India. Use of corrosion-resistant titanium alloy boiler tubes in power generation has good potential (Subbarao, 1992). Capability to design steam condensers exists at BHEL, which can be harnessed (SAC: Report to PM, Vol. I, 1990). A new plant to produce titanium sponge is expected to be commissioned by 1994-1995. The technology for this is developed indigenously by DMRL, Hyderabad. Similarly a plant to produce titanium mill products with a capacity of 200 tonnes is expected to achieve 80% capacity utilization by the year 2001 at MIDHANI, Hyderabad.

Application technologies such as fabrication, coatings and explosive binding are available in India. DMRL, Hyderabad is the main centre engaged in technology development for production of sponge, development of alloys, superplastic forming, skull-casting and powder metallurgy.

Action plan

(a) Application and fabrication-oriented technology for titanium will have to be developed.

(b) Processes such as hot isostatic pressing, cold isostatic pressing and technology required for casting should get greater emphasis. The active collaboration of DMRL and industry is required, to standardize the parameters for optimal efficiency.

(c) Components and subsystems containing titanium alloys required for aerospace, pumps and valves are being imported. The import of technology to produce these parts is required. These imported technologies can be assimilated, upgraded and integrated with domestic technology to suit our requirements.

(d) Titanium, with adequate raw material endowments, has high demand potential to substitute for materials with low corrosion resistance or low strength to weight ratio. We need to promote use of titanium products in a cost-effective way for structural applications, in power, aerospace and chemical industries. An Application Technology and Market Development Programme and commercial sponge production through coordinated efforts are needed.

Magnesium

The basic raw material for magnesium is sea water and magnesite. Being a country with a long coastline, India has good potential to tap sea water to produce magnesium. The total recoverable reserves of magnesite in India amount to about 222 million tonnes. Magnesium offers high strength-to-weight ratio and is an ideal material to replace many heavy materials such as cast iron. Hence, the demand for magnesium required for die castings is likely to increase in the near future. The domestic demand for magnesium in 1986 was around 1,000 tonnes. Major use is for aluminium alloying.

Magnesium in India is produced by Tamil Nadu Magnesium Ltd. (TMNL), with a capacity of 600 tonnes per year by electrolysis of sea water, (a technology developed by CECRI) and by Southern Magnesium and Chemicals Ltd. (SMCL), with a capacity of 600 tonnes per year using silicothermic technology developed by NML. The capacity utilization in these plants is less than 50% (Ganapathy and Sunderrajan, 1992). Lack of demand is the reason for low capacity utilization in SMCL and in TNML. "Teething problems" encountered in the scaling up of the technology constitute another reason for low capacity utilization in TNML.

Production of magnesium is highly energy intensive. The price of magnesium produced in India is higher than the international price, owing to high domestic power costs. Magnesium has good potential to replace many traditional materials economically. As India has good raw material potential, we can raise production. The basic technology is available in India. What is required are R&D efforts to increase productivity and energy efficiency as well as to bring down the costs. HAL, DRDL and DMRL are involved in developing magnesium alloy castings. DMRL and VSSC are working on magnesium-lithium alloys. However, these technologies need to be transferred to industry in the long run for commercial exploitation. Imported technology may also be called on to play a role.

Action plan

(a) There is a need to promote replacement of cast iron with magnesium and by-product-oriented technology development.

(b) Upgrading of the existing technology to reduce the cost of production and energy consumption is essential. Alloying and casting technologies need further development to achieve commercialization. DRDL and HAL should share their experience with other processors engaged in the aerospace and defence sectors.

(c) Smooth transfer of technology from R&D centres to industry is required.

(d) A coordinated programme, focusing on all aspects of the magnesium cycle is called for.

Strategic metals

The metals gallium, tungsten, lithium and nickel are strategic for India. Gallium arsenide is an important electronic material. It has the potential to replace silicon in the semiconductor industry. Though silicon has dominated the semiconductor scene for nearly three decades, in future, gallium arsenide in its pure and doped forms with superior properties will replace silicon in some critical applications (Subbarao, 1992). Red mud, a waste created during the extraction of aluminium, contains gallium and can be recovered. India can produce about 5 tonnes of gallium per annum, nearly a quarter of the global output (Ranganathan, 1992). Indian reserves for tungsten are very limited. Tungsten has applications in electronics and the defence sector. Since Indian ores are not good, technology to upgrade the ore is required. Lithium is another strategic metal which is important for India. Lithium when alloyed with aluminium forms a material which is suited to replace many of the conventionally used heavy materials in various sectors. Applications of lithium are in aerospace, as an anode in batteries and for aluminium production. In India, Bhabha Atomic Research Centre has developed extraction of lithium by a fused salt electrolysis process. DMRL is involved in scaling up this process. India has yet to develop the technology to extract nickel. Raw material availability is also very poor. Nickel is crucial for applications in stainless steel and super alloys. Substitution of nickel by manganese and chromium is possible in other applications. Development of rare earth products (e.g. magnets) and intermetallics also needs coordinated efforts. Work to produce these strategic materials to meet our needs (and possibly for stockpiling) needs to be promoted by the Government. Economics may be only a secondary factor in a national strategic materials programme. Defence and Atomic Energy can be the nodal agencies for this purpose.

C. CERAMICS AND GLASS

Technology

Ceramics can be categorized as conventional ceramics (tiles, sanitaryware, H.T. insulators and crockery) and Advanced Ceramics (electronics, structural, optical, etc.). The conventional ceramics industry in India showed significant growth over the last 40 years. The technology, equipment and machinery were mainly imported. The raw material potential for conventional ceramics in India is good. However, owing to the incompatibility of raw material with the imported equipment, the capacity utilization remains low. Urban-based demand and high fuel costs aggravate the low capacity utilization. In developed countries, advanced ceramics have been identified as materials with high potential to replace many conventional materials for a variety of applications. As a result, R&D efforts to improve the performance and to understand the structure-property relationships are being widely undertaken. Thus, the market for advanced ceramics in developed countries is being well established. Indian efforts towards establishing a market for advanced ceramics have yet to commence.

Glasses also can be classified as conventional glasses and advanced glasses. Conventional glasses are comprised of sheet glasses, bangles, light bulbs and tubes, container glasses, etc. Advanced glasses includes laser glasses, optical glasses, radiation resistance glasses, communication fibre, etc.

Production of conventional glasses has increased several-fold (0.30 million tonnes before Independence to 11.5 million tonnes during 1987-1988) with the advent of modern technology and increase in the scale of operations. Indigenous capability is strong except for manufacture of the modern machinery required for the fabrication of finished products. Technology has progressed to such an extent that India is even venturing to start glass industries in neighbouring countries (Sarkar, 1992). The trend in many countries is to reduce the production cost, especially fuel costs, through furnace control systems. Sheet glass manufacturing in India uses old technology which requires finishing by grinding and polishing. Float glass, a newer concept, is replacing plate glass and to some extent sheet glass. This process enables continuous production and the increase in output can go up to 500 metres per hour. Though the technology is more than three decades old, in India not a single plant exists. Otherwise, use of this technology could meet our domestic and export demand.

Production of advanced glasses requires advanced processing techniques, primarily in platinum containers with electrical resistance/induction melting devices. The demand for these glasses is very low, as is that from the defence sector. All these glasses, except communication fibre, are strategic in nature. India has developed the technology required to produce these strategic glasses. Foreign technology is used for communication fibre production. Indian institutions have been working on the development of this technology.

R&D facilities in the country related to ceramics and glass are primarily available in CGCRI, a CSIR laboratory. Few industry establishments have strong R&D centres. BHEL and ACC Ltd. are notable examples of establishments with strong ceramics R&D programmes. The imported technology to produce conventional ceramic products has not been assimilated. Similarly, in the case of glass, there are no effective industrial R&D centres. Industry links with CGCRI to solve the technical problems faced by the industry are also very weak (Ganapathy and Bhatacharyya, 1991b).

Raw material preparation, processing and final sintering and melting at high temperatures require lot of energy. In the conventional ceramics industry in particular, pottery units depend mainly on old down draft kilns fired with coat for long duration. This process is highly energy intensive and the wastage is very high, apart from creating high levels of air pollution. Efficient systems such as shuttle kilns are developed in advanced countries. Waste heat recovery mechanisms can also save energy consumption considerably. As an alternative method, application of microwave energy is being evolved in the glass and ceramic industry. The costs in this case are high and efforts are under way in developed countries to make this system more cost-effective. In the coming decades this is likely to be applied more in the ceramics industry.

Action plan

(a) There is a need to standardize the quality of raw materials required for the conventional ceramics industry. Variations in the quality of inputs create large-scale fluctuations in the quality of products.

(b) For advanced ceramics, India is endowed with good raw material reserves. Industrial exploitation of the process technology to convert these raw materials into high purity material is, presently, very poor. Import of the basic technology and further modification to suit Indian conditions along with mechanisms to transfer these technologies to industry are required. Microwave sintering in ceramic processing can bring down the energy intensity considerably. Efforts to enhance the cost-effectiveness of this application are needed. There is a need to promote integrated, interinstitutional efforts in priority areas such as insulators, ferrites, capacitors, high purity oxides, zirconia ceramics, etc.

(c) At present, the ceramics industry depends heavily on imported machinery and equipment (e.g. energy-efficient tunnel kilns, high temperature burners, hot isostatic presses). Efforts to manufacture the equipment locally are neglected. For the healthy growth of this industry, it is essential to make efforts to manufacture some of the equipment in India.

(d) There is a need to create a Ceramics Development Council with the following functions:

- To identify promising technologies and their applications for dissemination.
- To promote commercialization of the technologies identified.
- To generate financing for such projects and to identify groups to implement such projects, collaboratively.
- To monitor progress and coordinate related activities of each project.

Wood

Wood, as a material and fuel, has traditionally played an important role in men's lives to meet their daily needs. Over time, the supply of wood has become crisis ridden with the traditional source of wood, forests, being depleted at an alarming rate and the annual production of wood not adequate to meet the increasing demand. Though some substitute materials have been identified for specific end-uses, there is no universal substitute for wood. Wood is situated very favourably in performance and cost-effectiveness in comparison with metals and plastics. However, wood composites can substitute for hard wood in many of the applications.

Traditionally, wood is used in packaging, agricultural implements, the match industry, the plywood industry, paper, the sports goods industry and as fuel. Broadly, the use of wood can be classified under industrial wood and firewood. Industrial wood is processed through sawmills before it is used in many sectors. Because of its fibrous structure, the mechanical properties of wood depend mainly on its fibre or grain orientation with respect to applied force. A look at the nature of wood utilization and serious supply constraints shows that technology requirements are mainly for increasing timber yield, efficient processing, improving properties and production of wood composites.

Technology

Felling trees is now done by handsaws. Earlier, axes were used. To transport logs, convenient shapes are hewn by axes and saws. The loss of wood at this stage is 20-30%. However, the earlier practice of using axes is increasingly giving way to pitsawing to give the required shape for easy transportation of logs. This has helped to reduce wastage. About 60% of the industrial wood undergoes sawmilling operations to get the required size and form. Sawmills in India are mostly small-scale units, employing highly labour-intensive old technology (Srinivasan, 1992). Wastage at this stage is estimated to be more than 40%.

In an era of diminishing supplies, it is necessary to generate wood from non-forest sources for industrial wood and firewood. In the case of industrial wood, such plantation timbers are mostly short-rotation, fast-growing species which may create durability problems. In the case of industrial wood procured from forests also, external forces affect the durability.

Forestry education and research in India is being overseen by the Indian Council of Forestry Research and Education (ICFRE). Training programmes, both formal and informal, are continuing, and are being conducted by various institutes mainly in forestry management. The Forest Research Institute in Dehradum undertakes research activities on different aspects of forestry. The Institute of Forest Genetics and Tree Breeding at Coimbatore aims at genetics and tree breeding. IWST carries out research on structure, physical and mechanical properties of wood, seasoning behaviour of timbers, wood preservation, chemistry of forest products, biodegradation of wood and other wood products, mechanical wood processing, etc. This Institute also acts as a consultancy organization to carry out projects to fulfil the requirements of clients. The Indian Plywood Industries Research Institute undertakes basic and applied research needed to enable the wood panel industry to become self-reliant and more sophisticated. This Institute also provides training of manpower and helps industry through technical services.

The existing institutional structure reveals weak linkages among the stakeholders. Linkage with industry seems to be very weak. Linkages among government agencies/institutes at the forest management stage seems to be strong. At the same time, training of manpower required for wood science and technology is very poor. Similarly, training of personnel at the industry level is also weak (Ganapathy and Padmanabhan, 1991b).

Action plan

(a) The efficiency of sawmill equipment, logging and extraction of wood will have to be increased.

(b) Wood supplies from non-forest alternative sources (plantations, etc.) should be encouraged.

(c) There is a need to import the technology required to produce flake boards, oriented strand boards and mineral bonded products for making wood composites and panel products such as particle or fibre boards and modify them to suit Indian conditions. Indian industrial structure requires machines for small capacity plants of 25-30 cu.m. per day. Technology absorption and innovation at the industry level can be promoted through extension services, etc.

(d) Excessive reliance on synthetic adhesives, especially those which are toxic, should be avoided by promoting the use of natural adhesives.

(e) A proper understanding of the extent and pattern of wood use by various actors is essential to conserve and replace wood with wood composites.

(f) Human resources development in wood science and technology at various levels in the end-use industry is essential to increase the efficiency of use and cost-effectiveness.

(g) Industrial extension and linkages are vital to promote innovations and competitiveness.

(h) Promotion of the use of preservatives and treatment techniques is vital to increase the durability of wood.

Polymers

Polymers are replacing many of the conventional materials such as paper, wood, jute, glass, cement and metals in diverse applications. Polymers can be used as adhesives, coatings, electric insulation compounds, etc. They are also used in the form of synthetic fibres, foams, films, sheets and pipes. Some of the polymeric products are toothbrushes, buckets, combs, packaging films, milk pouches, luggage, toys, furniture, gaskets, belts, lighting fixtures, electrical connectors, aircraft parts, automobile parts, etc.

Polymeric materials can be broadly categorized into thermosets, rubbers, elastomers and thermoplastics. Manufacturing and use of thermosetting resins are fairly well established in India. The technology for rubber and elastomers also exists. Thermoplastic materials have been the latest entrants and are replacing thermosets and rubber—mainly because of the flexibility of product design and high productivity in processing. Thermoplastics are of three types: high volume/low volume commodity plastics, medium volume/medium price engineering plastics and low volume/high price specialty polymers. In advanced countries, thermosets and thermoplastics were evolved in the 1930s. The 1950s and 1960s saw the advent of high performance engineering plastics and specialty polymers. In the last two decades, materials technology, processing techniques, machinery, applications research and product design have received a lot of attention. Mainly, the emphasis at present is on tailor-made or engineered materials, to suit specific end-use requirements. Microprocessor controlled machines, computer-aided materials selection, product design, mould design and novel processes such as structural foam moulding, multi-layer extrusion, blow moulding, reinforced reaction injection moulding have been developed in the last couple of decades. These developments helped to evolve tailormade materials to suit specific end-uses, reduce costs and improve properties, with a consequently wider market. There is a shift from commodity to performance materials. Polymer structural materials in engineering applications and components for electronics industry are being increasingly used.

In India, polymers made their debut in the 1970s with the establishment of major petrochemical complexes. As India was a late starter, a lot of effort was needed to absorb the technology (already well established in developed countries) to suit our socio-economic needs. At the same time, the versatility of polymer as a material with applications in various sectors was already established, which provided ample opportunities to choose priority areas.

Indigenous manufacturing capability for polymers is currently restricted to commodity polymers such as LDPE, HDPE, PP, PS, HIPS, PVC, etc., and a few engineering polymers such as ABS, Nylon, PETP and PBTP. The process technology required for PTFE and PPS in the specialty polymers category also exists in India.

The production of commodity thermoplastics has been established for 15 years in India. However, the quality of products is poor in comparison with international standards. Process control instruments to ensure consistent material quality and upgrading of technology through in-house R&D efforts are required. For engineering plastics, a deeper understanding of the processing science and engineering capabilities of these products is required. Greater product innovation rather than product imitation is called for. Development work on sophisticated and automated process equipment and tools for design and manufacturing needs to be undertaken (SAC: Report to PM, Vol. I, 1990). Strong R&D -industry interaction is required to achieve this objective (Nadkarni, 1992). In India, though some technologies are developed at the laboratory scale in various research centres, further commercialization and development of production engineering capabilities in the industrial sector are not taking place.

There is ample scope to reduce the material intensity. As India is material-dependent on petro-based raw materials, this effort should get priority. In the polymer processing industry there is a need for increasing the materials yield through process optimization and control.

At present, the facilities to train manpower in the field of polymer science and engineering for processing, technical marketing, product design/development and research are not adequate to meet the growing needs of the industry. The courses offered by most of the universities are highly slanted towards polymer chemistry. Training imparted in in-house training centres is inadequate, especially in terms of modernization and instrumentation (Ganapathy and Wadhwa, 1991b).

Action plan

(a) Technology to produce ethylene from natural gas is urgently required.

(b) Imported technology to produce polymer blends, alloys, composites, epoxy and polyimides/bismaleimide resins and for applications such as membrane separation, drug delivery, etc., will have to be assimilated. Product innovation through a deeper understanding of the processing science and engineering capabilities for specialty polymers is required.

(c) Development of materials processing, applications development and product design should go hand in hand with production engineering capabilities. Strengthening the linkages between R&D centres and industry in terms of identifying priority areas, funding sponsored research and sharing of infrastructural facilities and manpower can achieve this target.

(d) Use of polymers for agriculture (e.g. superabsorbers for water retention, polymer films to minimize evaporation) should be promoted, considering the vital role that agriculture would play in the future development of the country (Subbarao, 1992).

(e) Manufacturing of machinery and equipment required for injection moulding, multilayer extrusion, sandwich moulding, etc., should be undertaken.

(f) Further strengthening of the facilities for human resources development in in-house training centres of industry and in universities is required. Emphasis in academic institutions should be more on what is required by the industry. Processing, technical marketing, product design/development and research are not adequate to meet the growing needs of the industry. Skills in handling mechanized operations, automated production processes and management of electronic equipment including computers need to be developed.

Composites

Composites are emerging as advanced materials, ideal to replace many of the conventional materials owing to their superior properties that can be engineered at the production stage itself. Composites have made an entry into diverse end-use segments such as automotive, aerospace, chemical, marine, electrical, construction, consumer and sports goods, defence, etc. By the end of the century, it is estimated that the market for polymer composites will be around \$23 billion. In the case of metal matrix composites, the market is expected to reach \$450 million.

Matrices are homogeneous resins or polymer materials in which the fibre system of a composite is embedded. The most commonly used matrices are Ceramic Matrix, Metal Matrix and Polymer Matrix. The materials used for ceramic matrix are aluminium and silicon carbide. Metal matrix materials are mainly titanium, magnesium and aluminium and their alloys. Polymer matrices can either be of thermosetting or thermoplastic materials.

The most common fibre used in composites is glass fibre. Worldwide, initially the aerospace sector started using glass fibre reinforced plastics (FRP). Later on, other sectors such as the construction, transport and engineering industries started using GRP. Penetration into sectors besides aerospace is very slow in India (Balasubramanian, 1992). Although E. Glass fibre is manufactured indigenously, special grades of glass fibres are still imported.

Aramid fibres offer low density, high specific tensile strength, wear resistance and damping properties found to be ideal for tyre and rubber reinforcement ropes, armour, etc. In India, the aramid fibre technology developed at the National Aeronautical Laboratory (NCL) is expected to be commercialized soon.

Currently, carbon fibres are the best known and most widely used reinforcing fibres in advanced composites. The manufacturing technology for carbon fibres, although complex, is suited for large-scale production. Carbon fibres possess very useful engineering properties. Baroda is making the precursors for carbon fibres and a limited fibre production facility for defence needs exists. Natural fibres such as jute and bamboo have tremendous raw material potential in India. NCL is working on jute fibres as possible reinforcing fibres for composites. Having adequate mechanical properties, jute fibres seem to be a very promising reinforcing material for the future.

The processing techniques commonly adopted for composites are Contact Moulding, Compression Moulding, Resin Transfer Moulding, Injection Moulding, Pultrusion, Automotive Processing and Press Moulding. An important challenge in composites technology is to design an appropriate product for a specific working environment. Two processes that have been identified as suited for India are Resin Transfer Moulding (RM) and Reinforced Reaction Injection Moulding (RRIM) (Ganapathy and Wadhwa, 1992). Compared with other technologies, RTM and RRIM have several advantages such as relatively faster production cycles, good quality end-use products with better finish and low labour costs. Commercial production of prepegs of composites has not yet begun in India and most of the production is oriented for hand lay-up. Most of the industrial units for category I (low cost and low performance) composites are small-scale units and their knowledge/technical support level is low. For advanced composites, since the producers (in defence and aerospace) are actual users and, given the critical nature of the application, the knowledge/technical support is very high. Most of them have well established R&D labs.

Access to information on the performance characteristics relevant to local conditions and interplay of various parameters is not readily available to most of the processors, which has resulted in poor design of products. NCL and NAL are already making some efforts to overcome this problem for some products and end-uses. Development efforts are not taken up by industry since they feel that the market is not big enough to invest resources for technological development and product improvement. Some of the key problems are:

(a) The quality of polymer resins offered by many of the small-scale producers is not of acceptable or uniform standards.

(b) In many applications, the product design is not optimum because of lack of knowledge of materials characterization.

(c) A systems approach to new materials adaptation is rarely followed.

(d) There is a lack of manpower with sound technical knowledge and skills for composite design and processing technology.

NAL is developing technology to produce Kevlar type fibres. Hindustan Aeronautics Ltd. is concentrating on aircraft parts and ISRO and DRDL on missile components from composites. DMRL, Hyderabad and RRL, Trivandrum and Bhopal are concentrating on MMCs. Similarly, in the case of CMCs, CGCRI, Calcutta and DMRL, IISC have also been working in this area for quite some time. Research carried on at private R&D centres is on reinforced polymer composites having applications in automobiles and building materials (Ganapathy et al., 1991).

Action plan

(a) High-tech sectors such as Defence and Space are presently the major users of composite materials. A strong linkage of industry and R&D centres would help to develop a shared understanding of the potential of these materials to substitute for conventional materials economically. This can also lead to development of technologies that can be commercialized for wider applications. The conventional, high-volume FRP industry also needs strong support and incentives for innovation.

(b) For better access and information about composite technologies, applications, market trends and consultancy services, an information service is needed. Databases similar to those of TIFACLINE will be useful in organizing such a service.

(c) Looking at the raw materials potential, it is desirable to promote the use of natural fibres such as jute and bamboo as reinforcing materials. Efforts similar to those undertaken by NCL will have to be supported.

(d) Commercial production of prepegs will have to be promoted.

(e) Facilities for manpower development required for composites are inadequate. Training (both formal and continuing) as per the industry requirements will have to be undertaken jointly by high-tech sectors (defence and aerospace), academic institutions and industry.

(f) Further work on processing, especially RTM and RRIM, is necessary.

(g) Development of standards, testing facilities and quality assurance can pay rich dividends in terms of new applications and export potential.

Electronics materials

Materials required for electronics industry are diverse, and require high purity and specifications. The investment required to produce these materials is also very high. Because of the capital intensity and limited domestic market, most of these materials are not produced in India. Components are produced from imported raw materials, but now with the recent growth of the electronics industry, the demand for components is adequate to encourage production of raw materials within the country. The demand for silicon, gallium arsenide wafers, thick film circuit tubes, etched aluminium foil, capacitor foil, capacitor grade plan plastic films, self-bonding/self-soldering copper wire, copper foil and high purity ferric oxide is high enough to start indigenous production. Some other materials required for the electronics industry are silicon, ferrites, piezo-electric materials, the new generation of rare earth based-materials for making laser devices, tantalum to make high performance capacitors, selenium for rectifiers and photocopy devices, etc. Though these form diverse classes of materials, they have some common characteristics such as high value and short commercial life cycles, resulting in rapid price erosion. Manufacturing of end products involves a sequence of individually complex steps requiring chemical modification or synthesis of materials (Patil, 1992).

More than 80% of the materials required by this industry are being imported. Apart from quality problems, the cost of indigenous materials is two to three times higher and there is a substantial technology gap. In terms of resources, especially in the case of tantalum, gallium, iron oxide for ferrites, mica, etc., we have some comparative advantage. The Department of Electronics has initiated a programme to narrow the technological gap. R&D efforts in industry are very limited. Working Groups of the Electronic Materials Development Council (EMDC), through active interaction with industry, government agencies and academic institutions, have identified some thrust areas of technology for development of materials and components for the electronics industry. Some of the areas identified are GaAs and III-V semi-conductors, opto-electronic materials, sensor materials, MOS grade chemicals, and MOCVD chemicals. The laboratories of the Centre for Materials for Electronics Technology (C-MET), CSIR, DRDO and DAE are working on high purity metals and alloys and related products, tantalum (for capacitors), thick film materials, MOCVD and MOS chemicals, photoresists, special ceramics and rare earth materials. Other materials that are being considered are semi-conductor crystals, special materials for lasers, microwave applications, etc., and special chemicals and plastics.

Funds for development activities - both basic and applied research - are being provided by the Government. Industry's share in providing funds is very poor. Transfer of technology from R&D labs to industry is also very poor. The infrastructural facilities for R&D are underutilized and fragmented.

Pollution and waste management problems created by the electronics industry are insignificant. Similarly, the industry is not very energy-intensive. Since the volume of materials required is very small, materials conservation issues are also not so important for this industry. Substitution of materials takes place only due to the availability and need for better performance.

Indigenous materials development for the electronics industry has a potential mainly because of the present high reliance on imports and abundant raw material resources. The technology gap between India and the developed countries is very wide. Importing technology is expensive and it cannot be justified due to limited demand. This also results in a poor record of innovation. The present initiative taken by the Department of Electronics with the involvement of the Department of Science and Technology along with other technical departments of the Government of India, industry, etc., needs further strengthening to achieve better results.

Action plan

(a) There is a need to strengthen the existing linkages visualized in the Department of Electronics programme on electronics materials. A coordination group can be set up. Involvement of financial institutions is vital for commercialization. Partnerships and alliances should be promoted for achieving complementarity and synergy among various institutions, which are presently pursuing fragmented efforts.

(b) Awareness in industry about R&D programmes, expert manpower, material resources, market trends, technology and products is important. To facilitate smooth dissemination of such information, a National Information Bank on Electronics Materials should be established by the Department of Electronics and C-MET.

(c) C-MET should act as a nodal point to provide linkages among manpower and infrastructural facilities available at various sources for R&D work.

(d) The existing technology transfer mechanisms from R&D to industry is very weak. Pilot plants, under C-MET, should be set up to supply limited products for field trials and market development.

(e) Looking at the nature of the industry, it is essential to identify priority areas linked to a time framework. This should be an ongoing exercise. As of now, high volume items such as ferrites, laminates, capacitors, electronic ceramics, etc., appear to qualify as candidates for priority development.

D. THE NEED FOR A NATIONAL MATERIALS COUNCIL

The world of materials is characterized by certain trends. An analysis of this context is critical to fashion our materials programme to enable the country to become more competitive in materials. The trends are:

(a) Rapidly changing technology and shrinking time-lag between design, manufacturing and use.

(b) Declining material intensity of products and preference for high performance, high energy/information-intensive, customized materials.

(c) Accelerating resource and environmental crisis resulting in the dominance of the "sustainability" question.

(d) The emerging unity of materials Science and Technology (S and T), use (rather than material) focus, integration of activities in the "material" cycle ranging from design to disposal, globalization of technology and markets for materials.

(e) Liberalized economic policy regime, with freer access to foreign technology.

(f) Limitation of budgetary resources and reliance on market processes for generation of resources.

(g) Altered role for government to facilitate and orchestrate policies rather than direct intervention and investment.

(h) Need for a strong infrastructure for standardization, testing, human resources development and technical services.

(i) A high degree of uncertainty and flux in the social, economic and political environment, calling for "robust" strategies, valid under alternative conditions.

It is clear from a review of the state of materials in India that the country needs a coordinated strategy in materials, to be able to derive strong economic benefits from our work. Materials technology with all the linkages in the materials cycle remains the central instrument for acquiring a competitive advantage. We need an institutional mechanism to facilitate such a coordinated approach. It is argued here that we need a National Materials Council (NMPP, 1992; Subbarao, 1992) to achieve this goal. This Council can build linkages among existing programmes, fill in the gaps, provide critical advice to government and industry and help India become an important world player in materials technology-led industrial development.

The programme of the Council should consist of mutually reinforcing activities that can lead to synergy and cumulativeness. The activities should cover all aspects of the "material cycle" because it has been well established that "linkages" are the problem in materials S and T-based industrial development. Thus, for a composite technology development project, sponsored R&D by the Council, venture capital investment by a financial institution, continuing education by the training institution, documentation, information service, engineering consultancy or product design for the manufacture and development of a technology applications programme may all be called for.

The priorities for the programme should be carefully chosen. The criteria for choice can be:

(a) Global trends in technology and markets;

(b) Social and economic relevance;

(c) Synergy with other ongoing efforts;

(d) Cumulativeness to previous efforts;

(e) Probability of success or demonstrable impact in a short to medium term time frame (competitive advantage, cost reduction, substitution, superior performance, energy/resource use efficiency, etc.);

(f) Potential for building alliances and cooperative arrangements (through networking, joint projects) or institutional capability;

(g) Building a knowledge base.

The programme should be implemented by a new autonomous Council to be set up through a collaborative effort among industry, government, S and T organizations and financial institutions. It can be nucleated through the Department of Science and Technology, and managed by an independent Board. Based on the recommendations of the Scientific Advisory Council to the Prime Minister, an empowered Committee, chaired by the Cabinet Secretary, recommended in August 1989 that such a body be set up. With initial funding from the Government, it should be able to raise larger resources with the help of financial institutions, international organizations, industry, etc. The need to accord high priority to a few select areas and to focus our resources is central for the new Council. The present pattern of diffused and diluted efforts needs to end. The advances of Japan and the Republic of Korea clearly indicate the need for this "target" approach and not the approach of "additionality" which we are following now.

The Council should have the following broad objectives:

(a) Development of a knowledge base in materials S and T in India through R&D and education;

(b) Development of a long range plan through technology forecasting and assessment for development and use of materials;

(c) Promotion of an infrastructure for material S and T development (facilities, standards, testing, information services, human resource development, etc.);

(d) Sponsorship of R&D projects in materials (alloys, polymers, composites, ceramics, sensors, biomaterial, membranes, magnetic materials, etc.) and ensuring their use in industry;

(e) Organization and facilitation of collaborative efforts, partnerships or alliances on a complementary basis, of different institutions (S and T, educational, industry, etc.) to build institutional capability;

(f) Inter-agency coordination in materials science and technology;

(g) Integration of materials science and technology with corporate strategy at the industry level;

(h) International linkages development (import of technology, foreign investment, S and T cooperation agreements, etc.).

The Council can operate a Materials Development Fund for promoting applied research, design and engineering in materials jointly with financial institutions, which have pioneered various schemes in technology finance. The Fund can be used for promoting a set of integrated activities at all stages of the materials cycle (including pilot plants and technology application as well as acquisition, adaptation and improvement of imported technology). It may focus on a few priority areas which have a high, but as yet unrealized commercial potential in India.

E. CONCLUSIONS

This review of Materials Technology Status in India seeks to look at a few key materials and identifies strengths, weaknesses, opportunities and environmental changes in the world of materials. The need for a "materials cycle" framework in developing a materials technology strategy emerges across the different materials renewed. Outlines of action plans in various materials have been developed. The following areas appear to be crucial for our efforts:

- Raw material upgradation.
- Process/manufacturing technology development.
- Assimilation and improvement of imported technology.
- Recycling, by-product recovery and waste management.
- Comparative advantage (cost, scale, quality, performance, etc.).
- Value added production.
- Development of performance materials.
- Substitution, conservation and materials use efficiency.
- Human resource development.
- Infrastructure building.
- Application/market development.
- Structural change in industry.

The review also identifies the need for an integrated programme promoting industry - government partnership and the establishment of a National Materials Council to orchestrate and facilitate our efforts.

REFERENCES*

** Balasubramanian N. Composites - A Technology Status Report. Eternit Everest Ltd., Bangalore, 1992.

Ericsson Magnus. Minerals and Metals Production Technology. A Survey of recent developments. *Resources Policy*, December, 1991.

Ganapathy R. S. and Bhattacharyya S. Towards a Strategy for Ceramic Industry in India. A Report of the National Materials Policy Project, TIFAC, New Delhi, 1991b.

Ganapathy R. S. and Bhattacharyya S. A Strategic Framework for the Indian Leather Industry in the Emerging International Context. A Report of the National Materials Policy Project, TIFAC, New Delhi, (1991a).

Ganapathy R. S. et. al. Materials Research in India: An Overview. Background Paper for a meeting on Strategies for Materials Research held at Administrative Staff College of India, Hyderabad on March 12, 1991.

Ganapathy R. S. and Padmanabhan G. Towards a Strategy for Aluminium in India. A Report of the National Materials Policy Project, TIFAC, New Delhi, 1991a.

Ganapathy R. S. and Padmanabhan G. The future of Wood in the World of Materials. A Report of the National Materials Policy Project, TIFAC, New Delhi, 1991b.

Ganapathy R. S. and Sunderrajan S. Strategies for Magnesium. A Report of the National Materials Policy Project, TIFAC, New Delhi, 1992.

Ganapathy R. S. and Sunita Wadhwa. Strategies for Composites. Paper presented in the National Seminar on "Strategies for Composites", March 9-10, Bangalore, 1992.

Ganapathy R. S. and Wadhwa Sunita. Towards a Strategy for Polymers in India. A Report of the National Materials Policy Project, TIFAC, New Delhi, (1991b).

Indian Copper Development Centre. Towards a Strategy for Copper in India. Report prepared for the National Materials Policy Project, TIFAC, New Delhi, December 1991.

** Nadkarni, V.M. Polymers: An Overview. National Chemical Laboratory, Pune, 1992.

NMPP. Final Report of the National Materials Policy Project, TIFAC, New Delhi, 1992.

** Patil S. G. Electronics Materials: Technology Status and actions needed. Centre for Materials for Electronics Technology, New Delhi, 1992.

** Ranganathan S. Metals and Alloys: Indian Imperatives. indian Institute of Science, Bangalore, 1992.

SAC: Report to PM (Vol. I). "Advanced Materials: National Priorities". Perspectives in Science and Technology. Department of Science and Technology, New Delhi, 1990.

SAC: Report to PM (Vol. II). "Minerals Development". Perspectives in Science and Technology. Department of Science and Technology, New Delhi, 1990.

** Sarkar B. K. and Agarwal B. M. Ceramics and Glass: An Overview. Central Glass and Ceramic Research Institute, Calcutta, 1992.

** Srinivasan, V. V. Overview Paper on Wood. Institute of Wood Science and Technology, Bangalore, 1992.

Steel Authority of India Ltd. (SAIL) Corporate Plan 2005. New Delhi, 1991.

** Subbarao. E. C. Materials Technology Status in India. Tata Research Development and Design Centre, Pune, 1992.

** Thyagarajan G. Assessment and Forecast of Technologies for Leather Sector. Central Leather Research Institutes, Madras, 1992.

TIFAC. Development of Titanium in India. TIFAC:R:014. New Delhi, December 1991.

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* The references are reproduced as submitted.

** Papers specially prepared for this review.

Discussion of Part Two, Paper Two

Mr. Ghazi Derwish:

Q. Very interesting talk indeed. I have two points to make. The first is: how do you see the role of conventional materials in your materials policy? The second relates to the problem of transfer of technology, and industry and intellectual property, and what is the role of the transnationals?

Mr. R. Bassyouni:

Q. Do you consider the information presented in front of us your personal results or have these results been reported to the upper management?

I recently visited industrial sites in India and I know exactly what you are doing. Naturally, I have collected some information. I also have information concerning the training being conducted. According to my information, the figures you quoted in your talk are terribly high. During your presentation the gap between your sets of figures can more or less be compensated, as you said, by imports. From my personal viewpoint, yours is a very good example for study by ESCWA. You seem to have acquired technology; you have industrialized, but you are somewhat slow in action.

Ans. The first question is about transnational corporations and the role of conventional materials and transnational corporations. Now, every projection shows that conventional materials will continue to be important until the middle of the next century. In the foreseeable future, conventional materials—for example wood, leather or iron and steel—will continue to be very important to the economy. However, the rate of growth of conventional materials will be slower than that of very advanced materials such as polymers or composites. The base figures for the growth of such materials are very small, but the rate of growth will be higher. For example, demand for polymers is increasing at something like 15% every year, whereas the demand for iron is increasing only by 6% or 7%. This kind of difference in demand will continue, but since the base figures for the conventional materials are very large, they will continue to be very important the end of next century and some of the results show that conventional materials can be made to perform like advanced materials if you only use technology effectively. To give some data, for example, in wood, which is a very important material, 15% of the wood which we produce is wasted in the first two stages, that is, logging and saw milling. We have outdated technology and we want to improve this. It is a scattered industry, small-scale, and much of the logging takes place illegally. Through legislation and waste control we can improve the industry. If you look at the steel industry, raw material and consumption, or the aluminium industry, they are about 20-30% worse than elsewhere. I mean, if you do some comparison, you will find that this, in fact, is the situation, so technology can make these industries quite efficient and bring them up to international levels of consumption, and conventional materials will be important.

Regarding the role of transnational corporations and intellectual property, let us deal first with the transnational corporations. The current economic policy in India encourages multinational investment. The policy's encouragement for investment, particularly in value-added production stages, is of critical importance. In India, foreign investment is linked to technology more than finance. Although finance may also be important, policies welcome investment where technology is critical. In areas where technology is critical, particularly value-added types of production such as raw materials or improving energy conservation measures or design and process technologies, investment is welcome, and I think transnational cooperation will play a more important role than they played in the past. This is also partly related to the questions Mr. Hossain raised on the role of the public sector. In India, we have had a socialist economic policy for a long time where the public sector played a dominant role, especially in infrastructure, basic raw materials, roads and dams. Many public-sector firms are quite successful. Nevertheless, there are a large number of public-sector firms which are inefficient and sick, and now there are efforts to modernize them or close them down. This process will take some time. But the public sector has also had some positive aspects. It has developed healthy markets, basic capabilities, standards, patterns of trade and distribution, which are in the national interest. I think in some cases they set good examples for private industry to follow and to compete with.

The third question is the question which you raised about the results. The industrial capability of India is actually outstanding. We have done fantastic things; we have put satellites in space; we have launched missiles; we are operating nuclear power stations, etc. In comparison, the results are outstanding, and I am proud of them. But the point I was trying to make was that these outstanding results have not made our industry competitive. Trying to build up national capabilities and make policies to help industry and improve competitiveness are two different things. In fact, there is a disincentive to transfer technology to industry. We have made a study of this situation and it appears that if some scientists are working in industry transferring technology, their own career prospects are at stake. We have launched missiles, we have put satellites in the orbit, yes, but what has been the impact on industry? Has there been a big benefit? I would say no.

Paper Three

UNIDO INTERNATIONAL CENTRE FOR SCIENCE AND HIGH TECHNOLOGY AND INTERNATIONAL INSTITUTE FOR HIGH TECHNOLOGY AND NEW MATERIALS

K. Venkataraman
and
V. Kojarnovitch

I will share this presentation with Mr. Kojarnovitch, my colleague from UNIDO.

As you all know, UNIDO, the United Nations Industrial Development Organization, aims at promoting industrialization in developing countries by providing them with technical assistance. Technical assistance is a very strong component in UNIDO activities. At any given time, something like 1,200 experts are out in the field helping developing countries in various aspects of industrialization. It is no wonder, therefore, that UNIDO is very much involved in the field of industrial materials technologies. UNIDO, has had an extension programme in this field in various sectors. We have a metallurgical industrial section, an engineering industries section, and a chemical industries section which deals with petrochemicals, metallic minerals, building materials, and so on. The promotion of sectoral technology centres and sectoral programmes has been going on, as mentioned yesterday in the opening session. It was also mentioned that in the Syrian Arab Republic there is a project to help the glass industry. We have felt in recent years that we should have a trans-sectoral approach to this question; as opposed to an approach which deals with steel only, with paper only and with cement only. Because of the substitutability of materials, there is a need to look at the wood rather than the tree. Naturally, the trans-sectoral view becomes particularly necessary when we look at new materials and you can call them advanced materials or whatever. Now this is one of the several sectors in which UNIDO is trying to identify and implement projects to help developing countries. We have microelectronics programmes; we have biotechnology programmes; and now we have also raw-materials programmes. I would like to talk about what we consider as our present approach to the subject. This approach has of course to be modified in relation to the needs expressed by countries in relation to their own needs. But we have to start within an approach by which we can find where the comparative advantage of interventions and assistance will be useful.

Many of the new technologies are ones in which developing countries can build various capabilities because of international trade, industry and cooperation. These new technologies, come in all kinds of products, and of course, nobody is certain as to how these products are going to affect different countries. So countries have to take decisions in a context of uncertainty. You are going to have all these answers, you can't wait till you have made all the studies before you can acquire certain capabilities. At the same time, you have to go by a certain perspective of what your country wants and then relate it to what is going on. We are trying to ask the question: What is it that the countries in question can do? Where do they interfere? There are so many things, so many materials, so many electronics technologies, so many biotechnologies. What do you do? Where is the point of entry? We have been working on the basis that we have to identify the fundamental skills and manpower capabilities which are needed, which you will then be able to use for your own purposes depending on your situation, raw materials and so on. For example, in the case of microelectronics, we will talk of the design of integrated circuits and applications, specific integrated circuits and other things, as something basic, if you really want to develop significant capabilities. In the case of biotechnology, we talk of genetic engineering as a basic concept by which you will be able to get a certain capability to apply biotechnology for your own purposes. Similarly in the case of materials, we think that it is materials engineering which is a fundamental capability which has to be used because the most important feature of the materials revolution is the capacity to engineer materials for specific purposes. This gives a tremendous advantage; but then, if you have this advantage, what does one use it for? Is it to produce the same types of material which is being produced in various countries in the developed world or can you use them to develop and upgrade your own materials? So when we talk of new materials applications, there are actually two elements: the first is that we can use the new materials such as, let us say carbon fibre, for certain applications which are development-oriented, i.e. which are useful in developing countries. At the same time, we should also think of materials engineering to upgrade and improve the existing materials or create economies and improvements in the existing materials. So both these aspects need to be taken into account. We realize that this is a rather difficult area, even compared to areas such as biotechnology, in the sense that materials are spread everywhere: there are so many uses, so many industries. How does one intervene in this field? That is why we in the developing countries and in international organizations have to exercise a great deal of selectivity in intervening and selecting the kind of strategies they should follow. That is why we prefer to look at some of the fundamental elements of capability building.

There are three things which we have to take into account. One is the capability building which I mentioned, the second is the materials policy; and the third is the enterprises, which are really the agents of change. We often talk about these things at great length, forgetting the hero of the show. The hero of the show is the enterprise which is actually producing various things, incorporating them in products and so on. So there is a triangular relationship between capability building, materials policies and the actors at the enterprise level. Now, materials policy itself is a complicated subject. We had a workshop on that subject last year; we are bringing out the publication on that subject soon, but there is not much point in debating the materials policy. Should one have a materials policy? Implicitly or explicitly, people have. Governments have a materials policy, if they neglect certain things, that is also a policy, except it is an implicit policy more than an explicit one. Now, there has to be more and more explicit recognition in governmental policies of the importance of materials and this might not necessarily result in a materials policy statement or materials policy resolution and so on. It will be good if that is done, but sometimes the statements and resolutions have their own life in books and publications and not in concrete activities. The important thing is to incorporate relevant considerations into decision-making. For example, a large irrigation project involves a lot of cement or a lot of material. The question is: What are the engineering and design considerations? What is the best building material you can use? But you could also look into it from the point of view of advances made regarding energy inputs involved and so on. In other words, decision makers have to be increasingly aware of the importance of materials, whether for consumers of energy as factors contributing to the environment or, of course, in terms of technological sophistication, effectiveness and economy.

So at present we are working on information generation, dissemination and sensitization of countries, then capability building, promotion of centres and networks. All these subjects Mr. Kojarnovitch will deal with at some length. There is only one other point which I would like to stress, namely the mobilization of international cooperation, which is extremely important because our general approach in this field says that even though it will take 5, 10, 15 years for countries to acquire capabilities in these fields and really to apply them, they have to start now, they cannot delay these things because there is a time lag involved. Now, if you do not start at the beginning, then you have difficulties. So the question is whether developing countries can enter the building at the ground floor and then take a lift later on. This is where the capability building becomes extremely important, and I think the scientific community in the world has always been cooperative. Our experience in biotechnology, in electronics and in other fields has been that the international scientific community is extremely interested in helping all countries and in spreading knowledge. So the mobilization of the scientific and technological community is extremely important as also that of professional societies such as the International or American Society of Materials, the International or the UK Institute of Materials and other institutions. We therefore need a common endeavour, and this is what we are trying to promote. I would finally like to give you a general description of the International Centre for Science, and Mr. Kojarnovitch will complement it with more information.

An International Centre for Science in Trieste, Italy, is being promoted with the help of the Government of Italy. We expect contributions from other countries. The Centre aims at promoting research and training in certain important fields of modern and advanced science. The idea is very much that of Professor Salam, who has initially promoted it as the chairman of the scientific committee of the Centre with the objective of training and research, training through research or research through training. In other words, training in research. For example, you have training courses for researchers; they can also get associated with researchers who are working in specific fields. Now it also provides the short-term training courses. At the moment, the Centre is in its early stages of development. We are expecting at least $7.5 million to run the Centre. So far, $2.5 million has been secured. We expect to get more money by 1994 when the Centre will be opened. The Centre will have three important fields of operation: one is pure and applied chemistry (there will be an institute for that); the second for environmental sciences and the third will deal with technology and new materials. Now obviously, not all new materials can be taken up. We have identified superconductors, composites and optical fibres as operation areas and we are trying to interact with scientists and scientific institutes in developing countries, but, as I said, these are at the initial stage and we will have a scientific committee which will help to focus the activities of the Centre. Otherwise dealing with three big scientific areas with limited funds does not make much sense.

Mr. Kojarnovitch:

I would just like to complement a bit the introduction of Mr. Venkataraman, and to give you some information on other activities which are being carried out in the area of new materials, having had some experience in promoting technological advances in developing countries. We are also trying to transfer knowledge and information on the subject from developed countries to developing countries and between the developing countries themselves. Thus, we have activities concerned with monitoring technological advances and disseminating them through publications which UNIDO is issuing and distributing among developing countries, and also through workshops such as this one. Another direction is building up technological capabilities selectively depending on the needs of the country and on the policy of the country concerned. The response to country needs, mobilization of information and promotion of regional cooperation are the main components of our strategy. This is because materials science and engineering, as everybody emphasized, is multi-disciplinary in its nature and trans-sectorial in its impact. Another important aspect is to locate counterparts among businesses to link materials projects to investment, because otherwise it will be very difficult to implement such projects.

In addition to the International Centre for Science and High Technology, we are promoting the establishment of an International Materials Assessment and Application Centre, which is a little bit different from the other centres, e.g. social development centres, because this centre will have a techno-economic nature and it will be working in the field of techno-economic evaluation, assessment and forecasting for some particular countries or regions and would also cover some techno-economic aspects for what is going on in materials science, what the trends are, and what the economic implications are of development of such areas for particular countries. Another question which is of great importance to developing countries and which was raised today by Dr. K. Hossain is testing in new materials. This is a very important area, for until you characterize the material, until you test it in a proper way that is common both to producers and users you will not go into market with that material. Therefore, we started with a workshop in Asia on testing in relation with new materials. The participants expressed the idea that the developing countries should have made some input in the development of this testing and the development of standards for testing and evaluation and at the same time to work together jointly in this quite costly area to save some human and financial resources, to share experiences and also to work together in establishing some standards. The initiative, therefore, was taken and we have now completed the feasibility study for the establishment of the Centre. Nine developing countries were visited by two groups of experts for the project and every country visited showed great interest and support for the Centre. Furthermore, we have a plan to proceed.

In terms of mobilizing regional cooperation we are promoting the establishment of a regional network for materials technology centres in Asia and we are planning something similar for Latin America, probably early next year and for Africa as well. It was also urged at the conference on new and advanced materials in 1990 to cover another area which Mr. Venkataraman mentioned: this is materials policy issues which are very important because until you have a very clear policy regarding where to go and how to proceed, it will be very difficult to start with the development and production of any material. One usually begins with identifying the major concerns. This is what we have done and the draft report is completed and will be distributed soon. Another study we have completed relates to the development of composite materials. This study examines the local resources which one could utilize both in agriculture and industry for producing composite materials together with the environmental impact that it may create and the immediate applications of these materials.

Discussion of Part Two, Paper Three

Mr. Zaidan Younes:

Q. You have mentioned that UNIDO has set up an awareness system to link many developing countries with regard to advanced materials technologies. My question is: what is the perfect method for, let us say my institution or my bank, to benefit from this awareness system? I am working with the Industrial Development Bank of Jordan.

Mr. Venkataraman:

Ans. As it is, we have two types of awareness programmes: one is our industrial and technological information bank, which has a special component of materials-related activities. We have a special arrangement with the United Kingdom Institute of Materials and their materials information systems, and of course we have a good arrangement with the MIS (Materials Information Service) also. So, we can put you in touch with those institutions. In addition, we publish a quarterly awareness bulletin called "Advances in Materials Technology Monitor", which tries to capture the essential developments in any particular field of materials and make it available to the countries. Actually, this monitor has different material in each issue, because you cannot deal with all materials and all things in one issue. So, for example, our first issue about three or four years ago was on high-strength, low-alloy steels. Then we had one on high-temperature ceramics and so on. We monitor something like 15 or 20 journals in the field of materials and then we extract information from them, obtain permission—corporate permission where necessary—and then we put the package together and distribute it. This is a useful way of contributing to that.

Mr. Najeeb Abdel Wahed:

Q. I have a general question for UNIDO and ESCWA. What are your views on the possibilities and scope of cooperation between UNIDO and ESCWA in the area of technology assessment of new materials in this region, especially as we know that the Syrian Arab Republic and Egypt are already trying to obtain support for this issue?

Mr. Abdulla Babaqi:

Q. I think that UNIDO does not have good links with universities, at least in Yemen, perhaps because your relationship is probably confined to the bureaucrats in the Ministry of Industry and the research centres. We do not have any information about your activities; perhaps you could give some highlight on this.

Mr. Ghazi Derwish:

Q. We heard an interesting discussion just now on the international centres, but I am still worried about the mechanism adopted for the mobilization of the third world scientific community in the areas indicated, especially in the light of the experience of the Trieste centres which were referred to. I do not know if the Centre is planned or has actually been started by UNIDO as a different approach to the problem of mobilization of third world scientists and the one adopted by Mr. Salam at Trieste. The second question concerns the accessibility of advanced technology to third world scientists. How are we going to help the third world scientist regarding information on advanced technologies from the advanced countries?

Mr. John Wood:

It has already been stated that links with the Materials Information Service (MIS) are available, but that actually also links you to people in universities. In Europe, for instance, we have had three high-level groups come to my department to look at what we are doing via groups contacting the MIS and then moving onwards. So this does not just stop at the information side; it does link in, and from this we are developing joint Ph.D. programmes with universities in other countries and this will be part of a network. So this is wider than just information. I am hopeful that such cooperation will gain more importance.

Mr. Mohamed Kamel Mahmoud:

Q. What will be the UNIDO follow-up action to this workshop in our region?

Mr. Suham Al-Madfai:

Q. UNIDO is pursuing many activities in all the Arab countries, but I think that UNIDO should be more active in some areas of science and technology that concern industry; for example, R&D centres. Assistance should also be directed towards the important fields of new materials, especially advanced materials. However, for us there are other important materials, namely those which make use of agricultural waste. This is also an important type of material; it is not a new material, but it is important for the region, and to some countries it is new.

Mr. Ali Dajani:

Q. You referred to silicon manufacturing, silicon chips and so on. This is too expensive a project for developing countries to establish. They can depend on other countries, but let us proceed so that local technology can be adapted by the people according to their capabilities and I wish to allude to something which Mr. Wood said about mixing flour and water. In the Arab countries, we need to learn how to mix flour and water to make good bread, and there UNIDO and ESCWA should help.

Mr. Akram Karmoul:

I would like to comment on the first question regarding cooperation. If you remember in the opening session, we mentioned that cooperation between ESCWA and UNIDO had been going on for many years in several fields. I must mention that most of the cooperation and joint activities have been, in particular, with Mr. Venkataraman's division regarding the industrial technologies. I appreciate his efforts in this area. With regard to the follow-up stages of this programme, I am glad to see the interest it has raised. I would call this workshop an awareness-raising workshop and there will be follow-up activities. Regarding the question about the foundry which was raised by Mr. Ali Dajani, whether expensive or not, we had to study its feasibility. It was meant for all Arab countries to have one site for manufacturing and many sites for design and use.

Mr. Venkataraman:

Ans. Thank you, Mr. Karmoul, for partly answering the questions because it is important that from the side of ESCWA you were already able to refer to the cooperation that we have been having; and that cooperation will continue. It has been there in the case of electronics, for example. In fact, the silicon foundry effort was also a joint effort. There, I will also stress equally on design centres and not just the foundry, as was mentioned by the last speaker.

About the silicon chips being expensive: yes, they are very expensive if you want to produce them, but if you can buy those chips whose price is falling and design your own products and your own activities and applications, then there is some sense in that. That is why we wanted to introduce the concept of design centres. We had cooperation in the field of biotechnology. Now we are moving to the field of new materials and we certainly look forward to the recommendations of this meeting. In fact, what we intend to do depends on what you think we should be doing, and there, as I mentioned, it will be good to concentrate and identify some points of entry into the whole field rather than address various targets at random. We must have a specific strategy with specific inputs. Two important things will be necessary which were referred to in your questions. One concerns some kind of directory or inventory of materials research going on in the region. I am not aware of any publication, and a thing like this would be needed. Secondly, some kind of impetus to survey the natural resources of the region, which is partly UNIDO and partly not UNIDO, but it does not matter. The important thing is that the countries concerned should have a fair appreciation of the natural resources they have. These are important elements for starting a programme of action in the field of materials. Of course, we will have several other possibilities and actions including multidisciplinary institutional efforts and so on, but we would be waiting for you to come to this conclusion rather than for us to suggest it to you. Yes, we sometimes think that UNIDO is known everywhere, but then it is not; and it was mentioned that in Yemen in the university, there is very little information about UNIDO. The starting point for rectifying this situation is to put you on our mailing list for some of our important publications like newsletters and monitors, but it so happens that all United Nations organizations have to be intergovernmental organizations, the main link or chain of communication is with the Governments. But different Governments handle the information sent by us differently; some of them distribute it and some do not. That is why this link between scientists and the technology activities of UNIDO will be just as useful as links between scientists in the developing countries and developed countries, and we should improve the situation.

Now, the mechanisms for mobilization of the third world community: this is extremely important, and the interaction with the institutions has to increase. That is why I mentioned that when you come to industrial enterprises, whether it is a developed-country enterprise or the preservation of a developing-country enterprise, there is always the concern for secrecy; it concerns competitiveness and so on. So cooperation can be had only on certain monetary and commercial terms. You cannot expect them to cooperate out of altruism; it rarely happens, and generally it does not. That is why the cooperation with institutions and universities is extremely important, and as I said, I have this experience in the field of biotechnology and in other fields that the academic community is very willing and ready to cooperate, unless there is something against this with the research contract or it is something which is being done for the Department of Defence and so on. Then they will have a ban; it will be told not to type the information. Otherwise, there is a great deal of willingness, even in the field of materials. With Rutgers University, for example, I had a discussion with them and they would be willing to consider some kind of cooperation with the developing countries. They have two excellent institutes, one in ceramics. Similarly, I had a call from someone at Carnegie-Mellon University, wanting to have some cooperation, and here it was mentioned that from the United Kingdom several universities are already cooperating. We want to find ways of increasing certain cooperation between our own activities and the third world scientists. One of the things I have suggested is the International Centre of Science to prepare the directory of research institutes in all developing countries so that it can identify institutions with which it can cooperate, because as time goes on this Centre will have to use these institutes as venues for training instead of paying air fares to take everybody to Trieste for training. There could be such important training in various institutes.

The point concerning more action relating to industry is very well taken. We ourselves would like to align all our activities more and more to industry. Concerning the use of local materials such as phosphates, as I said, services have towards be made and we have to base our strategies on the basis of requests. If there is any specific request from Jordan, we will certainly pass it on to the people who are most competent to handle the question of phosphates.

Finally I have a small comment on direct contacts with the private sector. You see, UNIDO has had a kind of direct mandate for cooperation with industry for the last four or five years. We had direct cooperation with many industries. The only thing is that we still keep the Government informed, but we can enter into special trust fund agreements with the industry to cooperate, and phosphates is one of the areas in which already we have some cooperation. So this facility cuts the red tape to the extent possible, and secondly, it addresses the direct concerns of industry; and this kind of activity is now growing in UNIDO.

PART THREE

Paper One

NEW AND ADVANCED MATERIALS TECHNOLOGY IN EGYPT

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Introduction

During the last few decades Egypt has made significant advances in its productive and service sectors. It is currently producing and consuming huge quantities of materials and commodities. The awareness concerning the importance of new and advanced materials in the country, however, is still in its infancy.

Since the beginning of history, materials have been the main driving force behind the growth, prosperity, security, and quality of life for mankind. Only in the last 30 years, and especially in the 1980s, has the scientific foundation of materials science and technology begun to take its present shape and to achieve international recognition. This happened just as the field itself has expanded and began to contribute substantially to the development of the society. Without new materials and their efficient application, our world of new devices, machines, computers, cars, planes, communications and structural products would not have been a reality.

Presently, materials scientists and technologists continue to be at the forefront of these and other areas of science and technology in the service of society as they achieve new levels of knowledge and control over the basic building blocks of materials, namely, atoms, molecules, crystals and non-crystalline arrays.

This paper deals with case of Egypt regarding new and advanced materials. It falls into three parts: part one gives a brief description of the status of materials technology in Egypt and includes references to specific materials technology projects and policy elements; part two shows the role of the National Research Centre (NRC) in research in materials technologies together with some recommendations for future work in this field; part three contains a suggestion for a materials technology strategy in Egypt.

A. CURRENT STATUS OF MATERIALS TECHNOLOGY IN EGYPT

1. *The main elements of national policy*

It has always been the objective of the Academy of Scientific Research and Technology to establish a National Research and Development Policy. A group of scientists, engineers and industrialists were requested to work on what was to be known as the National Technology Policy (NTP) and the objectives were formulated in two seminars.

A national seminar was held on 30 and 31 October 1982, and an international seminar was held on 24 and 25 November 1982. The exercise of discussions and seminars became known as the *Programme Towards a Technological Policy for Egypt.*

The subjects presented at the seminar included:

(a) Objectives and reasons for a legal framework for transfer technology. design, engineering and consulting offices;

(b) Programme for sectorial studies for the institutional science and technology infrastructure—light industries and heavy industries.

Although the work on the National Technology Policy did not include a special committee on new and advanced materials at that time, it did on more than one occasion refer to materials. A constructive dialogue on materials took place in all the committees. They concentrated primarily on substitution of local materials for imported ones and on the development and improvement of vital local materials.

2. *Specific materials technology projects*

The requirements for new materials technologies in Egypt are numerous. Some examples are given below. It is relatively easy to forecast needs in the case of modern industry. It would be difficult, however, to establish suitability or set up a time frame for commercial application.

Special steels. As the industry has progressed, a constant demand and need for special steels has been generated. Foremost amongst these steels are those used in producing tools, punches and dies. At first the industry imported its requirements; later a manufacturing ability emerged using imported steels with local design and implementation.

Fibreglass. The use of fibreglass has grown considerably; it is used in many industries ranging from blades for windturbines to tanks and containers. Its use has spread to bus bodies and engineering products with complicated shapes. Unfortunately, there is no local production of fibres, matting or resins.

Carbon fibres. Though the industry is aware of the applications of carbon fibres, no attempt has been made to enter this field. However, there has been considerable discussion on procuring a research centre complete with a pilot plant. UNIDO has erected similar units in India and China. Such a unit would result in a better understanding of this new technology.

Optical fibres. It is indeed paradoxical that a country such as Egypt, which has so much sand and appropriate sand deposits, has not been able to develop a quartz manufacturing base. A giant float glass project is planned, and the studies have been completed. A second step into optical fibres is not in sight because of the high investments and small demand.

B. SPECIFIC MATERIAL TECHNOLOGY PROJECTS IN EGYPT

1. *The salines project*

The salt industry has been known in Egypt for 7,000 years. The ancient Egyptians produced their salt requirement from salt water, rocks containing salt, salty plant stems or the salt mine at Wadi El-Natroun Depression. This industry has continued to the present.

El-Mex salines were established in the 18th century. Therefore, the production of common salt (NaCl) from Mex salines comprises the oldest commercial industrial exploitation of mineral resources in Alexandria, where solar energy is used to concentrate the sea brine as a first stage.

To enhance the salt industry and to satisfy the local demand for the chemicals which accompany sodium chloride in sea water, there is an expansion programme to add new capacities and new products such as dead burnt magnesia from the Mex-salines bittern.

The recovery of chemicals from sea water presents two principal problems. The first one is the removal of the bulk of the water. The second is the separation of the chemical components into useful end products. The most practised technique for the separation of the salts is fractional crystallization by solar evaporation. This procedure is the most economical process for eliminating the bulk water contained in the sea water and salt out the major sea water components. Hence the capital cost of one sea water bittern component recovery is often related to the concentration factor of the used bittern. Therefore, high concentrations are preferred, as, for instance, the capital cost of MgO recovery from sea water bittern, which with a concentration factor of 30 to 1, is 30% less by than that required for the original diluted sea water.

New technology has allowed such operation of a solar salt facility to be commercially possible for both essential salt and the by-product recovery from sea water. The range of materials which can be economically recovered from sea water is not limited to sodium chloride, potassium, bromine and magnesium; there are also possibilities for extension of this list in the foreseeable future by processing the sea water according to the new technology.

It is clear that a sharp difference exists between the five valuable substances in sea water. The six elements, or five compounds (sodium chloride, sodium sulphate, magnesia, bromine and potassium) represent approximately 98% of the total mineral value found in sea water.

Magnesium compounds are among the most abundant materials known to man. It has been estimated that 1.306×10^6 metric tonnes of magnesium are present in each cubic kilometre of sea water.

2. *Recommendations concerning the project*

The project capacity was estimated on the following assumptions:

(a) The production of 3,000 tonnes/year (t/y) of magnesium metal from which about 1,500-2,000 tonnes/year will be exported to Arab countries, especially the Gulf countries, which own two aluminium plants producing 300,000 tonnes annually. The balance of the magnesium metal produced will be consumed locally;

(b) The selling price of the magnesium metal was defined to be the same for the local market as for the export market, at LE (Egyptian Pounds) 10,000 per tonne to encourage local alloy producers to use magnesium metal in their products;

(c) The production of chlorine gas at a sellable level of 6,000 t/y, which is commensurate with the demand in the local market. The selling price is estimated to be the same ex-work price offered by the Misr Chemical Company i.e., LE 900/tonne;

(d) The production of the 2,000 t/y of magnesium chloride required to satisfy the local demand for the oxychloride cement and chemical industries. The selling price is estimated to be LE 500/tonne, which is equivalent to the international prices.

3. *Refractories*

Refractories are materials which withstand corrosion and other destructive forces at high temperatures. In all forms of metal processing there is an absolute dependence on refractories; a refractory product is essential for containment, treatment and safe handling in the various stages of refining. The strategic significance of refractories to the manufacturing industry and to the economy as a whole is underlined by the fact that without refractories there could be no steel production. Furthermore, refractories are of key importance in the manufacturing of cement, glass and ceramics, in power generation and in the oil-refining and petrochemical industries. Thus, refractory technology is fundamental to the success of the economy.

(a) *Raw materials*

Refractories are made from a wide variety of raw materials, including silica, zirconia, alumina, mullite, kaolinite, kyanite, graphite, dolomite, magnesite, and chrome ore. Egypt possesses some of these materials, whilst others may be purchased from overseas. Almost all refractory raw materials must be processed or refined to eliminate impurities and attain the required physical and chemical properties. Materials such as magnesia, dolomite and alumina, for example, will be fused, "dead-burned", sintered or calcined at temperatures up to 2000°C to give the desired characteristics for use in refractory products.

Natural refractory materials of sufficient purity to meet increasingly high standards are scarce. Suppliers of refractory raw materials and the manufacturers themselves are engaged in a continuous programme of evaluation to find new sources of quality raw materials.

(b) *Types of refractories and their applications*

Wherever high-temperature processes are involved, refractories are necessary. Several hundred kinds of refractories are in regular industrial use. Refractories are produced either in the form of chemical bonded, direct bonded or prefired shapes such as bricks and crucibles, or in the form of mortars, granular materials and other monolithic materials. Refractory mortars comprise a wide range of high-temperature jointing materials available for laying all types of refractory brick.

Within these categories there exists a vast range of products conceived and expertly designed for particular uses. In their various shapes and forms, refractories are essential to the construction and operation of aluminium melting furnaces, boilers, coke ovens, blast furnaces, basic oxygen furnaces, electric arc furnaces, ladles and ladle arc furnaces, continuous casters, steel reheating furnaces, foundry furnaces, copper converters, glass melting furnaces, vertical shaft kilns, rotary kilns, tunnel kilns, shuttle kilns, and kiln cars.

In Egypt a comprehensive study was carried out to estimate demand for magnesium oxide, which will reach 34,318 tonnes by the year 2000. The Egyptian Company for Refractories has already impressive quantities.

4. *The black sands*

Here, laboratory and pilot scale test work has been successful and has shown that the deposit is amenable to conventional processing techniques. Zircon and rutile concentrates have been produced to international specifications, but further work must be done.

5. *The island of Zabargad*

Zabargad is a deserted island in the Red Sea where traces of light rare-earth elements (such as La, Ce, Nd, Eu) as well as transition elements (such as Ni, Cr, Co). No further interest has been shown due to the remoteness of the island and finances.

C. Resources and materials needed

Egypt's mineral wealth consists of metal ores, chemical elements, precious stones, metal sediments in and on the ground, as well as mineral waters and salts. Quarry products include metal bearing stones, dolomites and silica sands for the manufacture of glass.

The search for mineral wealth continues in stages as capital and expertise, as well as the necessary infrastructure, are not sufficiently available.

The companies are in both the public and private sectors. Public business sector companies in the extractive field operate under the Ministry of Industry.

1. *The ore sector*

Planned targets relate to the development and execution of the following:

(a) A factory at Abu Zeneima in South Sinai will produce 14,000 tonnes of ferromanganese (75%), as well as 12,000 tonnes of iron ore;

(b) The gypsum project in the Delta will produce 360,000 tonnes of different types of gypsum;

(c) The Magara Coal Mine in North Sinai will produce 310,000 tonnes of coal, to be raised to 500,000 tonnes;

(d) Other projects include the annual production of 190,000 cubic metres of foundry sand near Cairo and 20,000 tonnes of bentonite in Fayum;

(e) Geological survey and exploration in the western and eastern deserts, the coal and tin projects at Elagala in Sinai;

(f) The nuclear organization projects, which include radiation surveys in areas where mineral resources are believed to exist;

(g) The development of black sand areas as a source of radiation and the extraction of uranium as a by-product of phosphate mining. Special attention has been given to the search for sulphur, tantalum, niobium, naphthalene and black sand. This has been carried out in cooperation with some American and European companies.

(a) *Contribution of the mineral resource sector*

The sector contributes by supplying many ores needed by industry. Its services to the construction and building sector have included the discovery of new gypsum resources and materials needed for the cement industry.

The sector carried out research and studies in different governorates to discover new resources of clay, sand and energy, or means of saving energy, and has contributed to such projects as the High Dam, the Cairo subways and the El-Katara Depression development.

(b) *Contribution of the mineral resources sector to the industrial sector*

(i) *Iron ore*

From 1940 to 1952, reserves in Aswan were estimated at 20 million tonnes. In July 1958 the ore began to be exploited as the first stage of the Helwan steel mills was completed; those deposits have since been exhausted.

In El-Baharia Oasis exploration started in 1954 and provides the bulk of ore for the iron and steel industry. The following are the results of this exploration:

(a) Ghorabi Mountains: reserves estimated at 55.8 million tonnes with 48% iron content;

(b) Nasser Zone: reserves estimated at 29 million tonnes with 44.7% iron content;

(c) El-Gadida Zone: reserves estimated at 131 million tonnes with 54.7% iron content. Since 1973 the El-Gadida mines in El-Baharia Oasis have started supplying the high furnaces in Helwan;

(d) El-Hara Zone: reserves estimated at 40 million tonnes with 43.7% iron content.

(ii) *Limestone and dolomite*

(a) The El-Rafaee area supplies the high furnaces of Helwan with limestone;

(b) Exploitation of the Bani Khaled (El-Minya) Zone is intended to meet requirements arising from the expansion of the iron and steel plant at Helwan. Limestone deposites are estimated at 35.5 million tonnes;

(c) Dolomite from the Ataka Mountains is used in the iron and steel mill.

(iii) *Manganese*

The main source of manganese in Egypt is the Ombegma area of the Sinai Peninsula. The Sinai company for manganese was exploiting the area.

(iv) *Ores for the ferrosilicon industries*

(a) East of Aswan there are quartz deposits estimated at 2.8 million tonnes. The material is the source of silica needed by the ferrosilicon factory at Aswan;

(b) In Omheglig, south of the Edfu to Marsalam Road there are quartz deposits estimated at 13.4 million tonnes;

(c) In South Edfu, deposits of silicate-bearing stones were estimated at 2.5 million tonnes. The material is suitable for the manufacture of ferrosilicon.

(v) *Ores needed for phosphatic fertilizers*

(a) Various locations in the Nile Valley between Edful and Kena contain phosphate. Approximately 1,560 million tonnes of precipitates are thought to be located in the Nile Valley east of El-Mahameed Zone, between North Esna and South Edfu, with proven deposits of 237.5 million tonnes. There are also reserves west of El-Sabawia, El-Karayat and Abu Sabona east of the Nile;

(b) Reserves of phosphatic precipitates in the Red Sea area are estimated at 14.5 million tonnes plus 34.3 million tonnes in the El-Hamrawin Zone;

(c) Reserves of phosphatic precipitates in the New Valley are estimated at 1,000 million tonnes with an average content of 25.56% phosphate. The largest project in Egypt is Abu Tartur.

(vi) *Raw materials for ceramics, porcelain and glass industries*

(a) Deposits of kaolin, a material used in the ceramics and porcelain industries, are estimated at 16.5 million tonnes;

(b) Deposits of silica sands in the Abu El-Darg areas are estimated at 4 million tonnes. The material is useful in the glass industries;

(c) Glass and sand east of Edfu are exploited to meet the demand of local industries;

(d) Estimated deposits of sand south of Zafarana run into the millions of cubic metres with a purity of 99.88%.

(vii) *Chemical industries raw materials*

Limestone is found in some areas along the road between Alexandria and Marsa Matruh. Deposits are estimated at over 12 million tonnes. The substance is suitable for the production of sodium carbonate. There is another deposit of 2 million tonnes east of Helwan is suitable for the sugar industry. A deposit of 835,000 tonnes of sodium sulphate will be used in the sugar industry.

(viii) *Contribution of the mineral resource sector to the construction and reconstruction sector*

(a) Gypsum deposits estimated at 4 million tonnes are located southeast and east of Fayum;

(b) At Suez, there are 380 million tonnes of reserves of limestone and 67 million tonnes of reserves of clay for the cement factory;

(c) The raw materials needed for the cement industry are located in Assiut, where 50 million tonnes of limestone, 10 million tonnes of clay and 1.5 million tonnes of sand have been determined to be suitable for the cement industry;

(d) The El-Amed Zone has limestone deposits estimated at 3 million tonnes; and in El-Gribaniat deposits are estimated at 12 million tonnes;

(e) The supply of limestone to build new towns, such as the suburbs of Cairo.

(ix) *Contribution to the energy resource sector*

The mineral sector contributed its experience and efforts to the task of supplying coal energy. It also contributed to the technological development of the energy sector. Magnesium metal is being increasingly used in many industries and products.

The projects which have been planned to establish new and advanced materials technology in Egypt include the existing ferrosilicon project in upper Egypt and the dead-burnt magnesia recovery from the Alexandria salines, which is estimated to produce 3000 tonnes/year of sands at Rosetta. These projects face financial constraints. For the salines project, for example, a total investment of LE 100 million is needed, of which 50% is to be in foreign currency. There will be a need for export as local demand is not sufficient for economical production. Approximately 1,780 tonnes/year are to be exported to Arab countries. Most of the investment need is for infrastructure, as most materials projects have proved to be energy-intensive.

2. *Effects of the technology*

The ferrosilicon industry could, of course, hold grave consequences for the environment. It is no secret that the Egyptian plant has had its share of environmental problems. It has, on the other hand, provided employment in a primarily agricultural area of the country.

In the case of the salines project 6,000 tonnes of chlorine gas will be produced annually and will contribute to completing the drinkable water networks all over the country. Chlorine gas is essential for water treatment. The magnesium metal project will provide 828 tonnes per year for aluminium alloys, 300 tonnes for the iron and steel industry, and 120 tonnes per year for automotive industries.

D. Research in new and advanced materials technologies in Egypt the role of the National Research Centre

1. *Historical background of the NRC*

Egypt established the National Research Centre (NRC) in 1956 with the objectives of creating a national capacity to support public sector efforts in developing a national technological base to generate knowledge and technology needed for the production and service sectors.

In 1971, the Egyptian Government decided to establish the Academy of Scientific Research and Technology (ASRT) in order to strengthen the institutional aspects of science and technology in the country and to better relate R&D efforts to national needs. In 1975, Egyptian economy policy changed to an "open door policy", and private-sector and foreign investors were encouraged to establish production projects. In the same year, the NRC programmes and objectives were tailored to these objectives.

2. *Scientific and technological policies of the NRC*

The basic orientation of research activities in the NRC lies in customer-oriented research to address the national needs more effectively. The NRC generally organizes its activities in eight research areas: rural development; food and agriculture; health and environment; technology transfer; natural resources; energy; computers and genetic engineering.

NRC research programmes are funded mainly through governmental and partially through bilateral research contracting with local or foreign agencies. Research activities are managed on contractual bases: in-house contracts; local projects contracts; contracts with foreign agencies.

In 1991/1992, a total of 292 contracts were carried out: 139 in-house, 119 local, and 34 foreign contracts.

E. NRC divisions and departments

At present, the NRC consists of 13 research divisions and 54 departments as follows:

	Division	Departments
1.	Chemical industries	Paper and cellulose; tanning materials and protein chemistry; polymers and pigments; chemistry of pesticide; glass, refractories and building materials.
2.	Pharmaceutical industries	Pharmaceutical sciences; therapeutical chemistry; chemistry of natural and microbial products.

	Division	Departments
3.	Textile industries	Dyeing, printing and textile auxiliaries; spinning and weaving; pretreatment and finishing of cellulosic fibres; protein and synthetic fibres.
4.	Food industries and nutrition	Food and dairy industries; fats and oils; food and nutrition
5.	Agriculture and biology	Botany; pests and plant protection; soil and water use; animal reproduction and artificial insemination; animal and poultry production and nutrition; parasites and animal diseases; agricultural economy.
6.	Engineering	Mechanical engineering; solar energy; chemical engineering and pilot plant.
7.	Medical sciences	Basic medical sciences; pharmacology; community medicine; child health; hormones.
8.	Environmental sciences	Water pollution; air pollution; occupational health and industrial medicine.
9.	Applied organic chemistry	Organic chemistry; biochemistry; chemistry of flavouring agents and related substances.
10.	Applied inorganic chemistry	Physical chemistry; inorganic chemistry.
11.	Basic sciences	Microbial chemistry; cytology and genetics; earth sciences; photochemistry; flora and plant taxomony.
12.	Physics	Solid state; spectroscopy; microwave; theoretical physics; electron microscopy and thin films.
13.	Genetic engineering and biotechnology	Cellular biology; human genetics; molecular biology; plant cell and tissue culture; microbial biotechnology; microbial genetics.

There is a materials testing laboratory, which serves six industrial areas; pharmaceuticals, textiles, polymers, ceramics, paper and leather in addition to biological fluids:

- Experimental animal breeding laboratory
- Medical services unit
- Experimental agricultural research stations for plant production, animal production and medicinal plants

- Systems and information research laboratory
- Textile pilot unit
- Food industries pilot unit.

During recent years, several research programmes have been established in different NRC departments to deal with new materials in a traditional way. At the beginning, research was mainly directed at technology transfer processes dealing with polymers, ceramics, glass, building materials and pharmaceuticals. In addition, some research results are already contracted to be applied on an industrial and production scale.

Awareness at NRC of international trends in the field of new and advanced materials, oriented its authorities to recognize this field, and a new department was created in 1991 with the aim of compiling experiences in one department and to orienting efforts and capacities to cater for local industries. The objective of this new department is to condense R&D programmes related to polymers, ceramics, metals and alloys, fibres as well as medical, electronics and engineering industries; and to cope with the recent international trend towards this sophisticated technology.

Some of the NRC activities in the field of ceramic materials are given below. In each case an outline of the particular ceramic material in question is given, followed by a brief account of the NRC activities in that area.

F. New and advanced ceramics and their applications

NRC has paid continuous attention to the follow-up of new trends in materials research. In the mid-1960s, a multidirectional programme was initiated in relation to sophisticated materials of the time. For example, in the field of ceramic materials, some important electronic materials were investigated. Barium titanate, a wonder material then and now, characterized by both a high dielectric constant and a low power factor, was studied for preparation, densification and properties (5).[1] The high grade TiO_2 of rutile sand, one constituent of the Egyptian black sands, was employed for preparation of both titania and barium titanate ceramic condensers (6-7). Stabilization of zirconia by CaO or MgO for the purpose of obtaining both high refractory and solid electrolyte materials was the goal of another study (8). Solid state ceramic electrolytes were the aim of another study, where synthesis, formation and stability of Na-, K-, and Li-β aluminas were investigated (9). The study resulted also in a low temperature sintering for preparation.

The preceding paragraph shows that advanced ceramics cover a wide range of applications: from vital and sophisticated components of aircraft and space shuttles to simple household instruments, and from the fields of electronics and telecommunications to dental and medical materials. Some of the work of the NRC in the area of advanced ceramics—namely high-technical, ceramics, electronics ceramics, and bioceramics—is presented.

[1] For the list of references, see page 391 *ff.*

1. *High-technical or engineering ceramics*

Relatively unknown by other than a few materials specialists at the beginning of the last decade, high-technical or engineering ceramics have gained increased attention in many countries in the world, particularly where developed mechanical engineering applications exist. New processing technologies, as well as improved fundamental understanding of these materials, allow engineers to take advantage of ceramics' superior wear resistance, high-temperature strength, and chemical stability while providing greatly improved fracture toughness.

Some members of the family of high-technical ceramics of great importance are briefly mentioned below:

(a) *Zirconia (ZrO_2)*

Zirconia is now used in a diverse number of applications which include ceramic pigments, glass and gemstone manufacture, electroceramics, engineering ceramics, thermal barrier coatings and refractories. We are concerned here with its engineering applications.

In addition to their high rupture and tensile strengths and high fracture toughness, zirconia ceramics display an elasticity comparable to that of steel, coupled with the low thermal conductivity needed for insulating functions and expansion behaviour similar to that of gray cast iron. These collective properties have nominated these ceramics to be "engine ceramics", i.e. ceramics used in building or tailoring of heat engines. Engine ceramics must stand up to a whole catalogue of collective stresses, strains, and service loads. They must satisfy the requirements that no metal could meet, since they simply go beyond the performance limits of the metal.

The price of ZrO_2, even when purchased in commercial quantity, can vary considerably depending on its route of manufacture. A low-purity zirconia may cost as little as \$2.00/kg, and a highly specified grade of stabilized zirconia designed for a specific use may cost in excess of \$50.00/kg.

Zirconia occurs in monoclinic, telragonal and cubic modifications. Ceramic bodies cannot be densely sintered without the addition of compatible lattice ions, such as those of Y, Ca, Mg and a few other rare earth elements, the purpose of which is to stabilize the tetragonal or cubic phase obtained at sintering temperature after it has cooled to room temperature. The properties of the ceramic material can be varied within wide limits, depending on the type and quantity of stabilizing ions.

Zirconia ceramics are classified according to the following types based on technical English usage:

CSZ: Cubic stabilized zirconia.
PSZ: Partially stabilized zirconia.
TZP: Tetragonal zirconia polycrystals.

In the NRC Department of Ceramics, a research plan has been completed in which CSZ was prepared with different doping ions using simple hydrothermal techniques (12,13).

Interesting results were obtained: a high degree of purity, homogeneity, and suitable particle size distributions to the stabilized materials at noticeably low temperature, circumventing the drawback of solid state preparation at high temperatures and the following crushing and grinding steps. The materials were characterized for their surface areas and reactivities (14). The high degrees of reactivity and large surface areas were reflected in the low temperatures of sintering that were needed to mature the ceramics fabricated from these materials (15). This latter result indicates the possible energy savings arising from the use of such homogeneous, finely divided, and reactive materials. The fabricated bodies were also investigated for their microstructures, by transmission and scanning electron microscopes, which have great bearings upon their accompanying mechanical, physical, and electrical properties.

Awareness of the industrial applications of both PSZ and TZP zirconia ceramics was the main incentive behind the adoption by the NRC of a comprehensive research programme to prepare these two types of materials in the Ceramics Department laboratories by aqueous chemical methods. The fine-grained materials that are expected through these method can play a marked role in improving the mechanical properties in operating bodies at high temperatures.

The two important sources of zirconia are baddelyite and zircon. Zircon ($ZrSiO_4$) is the most widely distributed of the commercial minerals and is the major source of the oxide. In Egypt, zircon is available in economical deposits as beach sand in "Rosetta" on the northern coast of the Nile delta. It is one of the major constituents of the black sands that deposit at the coast of "Rosetta" by the sorting action of the Mediterranean sea waves, with the heavy minerals carried by the flooding water of the Nile. The sands also contain other important minerals such as rutile, monazite, ilmenite, and magnetite.

The diversity of applications of zirconia as a raw material have led to the development of different process routes to its manufacture. The processes that are used to decompose zircon to yield zirconia are thermal and chemical routes.

In the NRC some experiments have succeeded in utilizing the chemical route to obtain zirconia from the Egyptian zircon sand (16,17). However, these results have not yet been put into production owing to lack of investment. In general, the chemical processing route accords great flexibility to zirconia manufacturing and leads to a range of designer zirconias that can be tailored to meet the requirements of specific industries.

(ii) *Transformation-toughened ceramics*

Transformation-toughened ceramics (for example transformation-toughened alumine [TTA]) have been developed in the last decade as a result of extensive research programmes to overcome the problem of brittleness of ceramics for specialized uses in the field of mechanical engineering. Transformation toughening of ceramics, also called dispersion ceramics, is based on the idea of dispersing fine zirconia particles in an alumina powder and subjecting a compact made of the resultant mixture to the maturing temperature (1500°-1600°C) to produce a ceramic in which all zirconia particles are in their tetragonal form. Normally, all ZrO_2 particles would increase in volume and revert to their monoclinic low-temperature modification upon cooling; but in the already consolidated sintered body, volumetric expansion is extensively precluded because the fine particles of zirconia are rigidly surrounded by the matrix. They remain metastably tetragonal because the internal stresses of the alumina matrix prevent transformation. Only the effects of external stresses, e.g. those due to mechanical loading of the component in question, can lead to so-called stress-induced phase transformation back into the stable monoclinic form. The volumetric expansion resulting from such transformation causes a build-up of compressive stresses which is responsible for the enhancement in strength and reduction in brittleness. This mechanism results in at least a tenfold increase in bending strength and higher levels of fracture toughness than those shown by the pure matrix materials.

The transformation-toughening principle is applied not only to alumina, but also to other important structural ceramics in need of a fracture-mechanical property at temperatures up to about 700°C, such as mullite and spinel, as well as to ceramics that can operate at temperatures up to 1330°C, such as silicon nitride.

The Egyptian Aluminium Company in Nagaa-Hamadi in southern Egypt, the largest aluminium producing company in Egypt, has decided to produce 10 tonnes/day of alumina, starting from January 1993, for special uses. Technical grade mullite is already produced in some Egyptian refractory factories. Also, in the NRC, a research project will be carried out on some transformation-toughened ceramics using nonconventional preparation routes, including a study on the major factors affecting strength and toughness of the materials. It is hoped that both the research and industrial efforts will be beneficial to the ESCWA member countries.

(c) *Silicon carbide*

Silicon carbide (SiC) does not occur in nature; it must be synthesized by a high-temperature chemical reaction. High quality silica, low-sulphur petroleum coke, and electricity are the major ingredients in the production of SiC.

High-purity SiC (99.8%) is light-green, and for 99% purity it is black. These materials are used for metallurgical, refractory and abrasive applications. High-purity SiC is used in special ceramics and as resistance-heating rods. Ultra-pure SiC is in growing demand for reaction-bonded silicon carbide (RBSC) for high-temperature mechanical applications.

Very fine high-purity reactive powders are obtained by synthesis through induction furnace, plasma-arc processes, batch reaction of silica and carbon in CO or an inert gas and decomposition of carbosilanes. For the manufacture of high-performance ceramics, these powders can be sintered, hot-pressed (HP) or hot-isostatically pressed (HIP). Prices for these sinterable powders range from $10.00/kg to $40.00/kg depending on purity and fineness.

The most critical SiC manufacturing issues in recent years have been environmental concerns as well as large cost increases for electricity in some areas. The former was the reason behind the closure of a number of plants in North America.

Research on SiC in NRC began at the end of the 1970s. It concentrated on synthesis of SiC from rice hulls impregnated with ferrous sulphate as a catalyst (18). This work was a part of a comprehensive project aimed at exploiting rice hulls, an agricultural waste available in large quantities in Egypt (400,000 tonnes/year), in the production of some ceramic articles. It can also be used as a source of energy by gasification or pyrolysis. The residue, which contains 50% carbon and 50% silica, can be treated under certain conditions of temperature, inert gas atmosphere and suitable catalyst to obtain the carbide. The exact conditions have been thoroughly described (19). This process has the benefit not only of producing valuable products, but also of avoiding pollution problems created during the burning of the hulls to silica.

(d) *Silicon nitride and sialon*

Silicon nitride (Si_3N_4) is a synthetic material which is made by a high-temperature chemical reaction between 1000° and 1600°C. Six processing routes have been used for production of high quality silicon nitride powders (20). Both the properties and production costs associated with silicon nitride powders are affected by the process used to form the powder. The methods are:

1. Direct nitridation of silicon powder, wherein high-purity, fine silicon powder is reacted with nitrogen gas at developed elevated temperature to create Si_3N_4 powder;

2. Carbothermal reduction, which involves the reaction between silica powder and nitrogen in the presence of carbon;

3. Vapour-phase reactions between silicon halides, such as silicon tetrachloride and silane, and ammonia;

4. Liquid-phase reactions, which involve the same reactants as the vapour phase except that the silicon halide is in the liquid phase.

5 and 6. Laser and microwave synthesis, which are laboratory-scale alternatives to the vapour-phase reaction process in which the reaction is induced using either laser energy or a low-powder microwave discharge. Methods 1, 2 and 4 are the most important and economical α-Si_3N_4. The other methods offer high-purity and ultrafine reactive powders but are more costly. Whiskers of α-Si_3N_4 are produced also by the same methods but with some variations in the conditions of processing.

Dense products of Si_3N_4 are made by nitrogen-atmospheric-pressure sintering, hot isostatic pressing and uniaxial hot-pressing. These dense Si_3N_4 bodies can have high hardness, high strength at high temperature (up to 1350°C), low density (3.2 gm/cm^3), low thermal expansion, good oxidation resistance, and a high fracture toughness for monolithic ceramic (4-11 MPa$\sqrt{m}$).

The key which unlocked the potential of ceramic diesel engines was silicon nitride. The continued improvement in toughness, better high-temperature creep resistance, and superior reliability with improved forming processes has led to the successful demonstration and production of heat engine components. The low weight, good shock resistance, and excellent wear resistance provide performance advantages compared to traditional metal components in piston engines.

Tool bits for machining of cast iron are made of Si_3N_4 with other materials. There are at least five domestic suppliers of tool bits in the United States. They are also manufactured in Japan, FRG, UK, and Sweden. Other products are being made from $Si_3 N_4$ include pump seals, rolling contact bearings, and several other wear parts.

Perhaps the disadvantage of Si_3N_4 that limits its use in heat engines is its high cost compared with the conventional metallic materials. The powder can be purchased from sources in Germany, Japan, Sweden and the United Kingdom. Prices vary from $20.00/kg to $350.00/kg depending on specified particle size and purity.

In the NRC, the same innovative method, i.e. the nitridation of the pyrolysed rice hulls in the presence of a suitable catalyst, has been adopted to prepare a good quality silicon nitride (18). The reasonable temperature of preparation offers another advantage to the low cost accompanying the low price of the agricultural waste rice hulls. The work represents a good base for implementing a comprehensive project towards preparation of α-Si_3N_4 on a large scale. Studies were also made of the properties of hot-pressed Si_3N_4 powders from different sources (21), the effect of mineralizers on the oxidation behaviour of dense Si_3N_4 (22), and the surface characteristics of the hot-pressed materials (23). Fibres of Si_3N_4 have also been obtained from the thermal conversion of Si-resins (24).

Sialons, combinations of silica, aluminium, oxygen and nitrogen, are often fabricated with Si_3N_4 as a raw material. The common commercially available dense material forms, sialons are in fact β-Si_3N_4 structures with oxygen and aluminium substituted for nitrogen and silicon. Sialons have been the subject of numerous research programmes to produce tough and more reliable structural ceramics. In this respect, the use of rice hulls for the preparation β-sialon showed good results in the NRC laboratories (24). A single-phase sialon was formed from the reaction of kaolin with cooked rice hulls in an NH_3 atmosphere at 1500°C through well controlled carbon/silica and alumina/silica ratios.

2. *Electronic ceramics*

Ceramic materials are unique in offering a wide variety of electrical properties. Billions of dollars are expended each year in the field of electroceramics in industry and R&D programmes. The multi-billion dollar electroceramics market includes, among others, $BaTiO_3$ (BT) capacitors, PZT transducers, ZnO varistors, Al_2O_3 packages, PTC thermistors, High Tc ceramic superconductors. BT capacitors, piezoelectric transducers and PTC thermistors make use of the properties of ferroelectric perovskites with their high-dielectric permittivity, large piezoelectric coefficients, and anomalous electric conductivity. Grain boundary phenomena are involved in boundary layer capacitors, varistors, and PTC thermistors; the formation of a thin insulating layer is crucial to the operation of the later three electroceramic components. Ionic conductivity is used in oxygen sensors and batteries. Stabilized zirconia is an excellent anion conductor, and β-alumina is one of the best cation conductors.

There are numerous electronic ceramics and their applications are even more numerous. Some of these advanced ceramics are discussed briefly below.

(a) *Barium titanates and related materials*

Barium titanate ($BaTiO_3$) is the most famous of the perovskite structure materials. It has found numerous commercial applications, most of them based on its ferroelectric and piezoelectric properties. They include ceramic capacitors, filters, measuring devices and ultrasonics. $BaTiO_3$ can form solid solutions with Sr, Ca, and Mg titanates giving ceramics having different curie temperatures and hence more applications. More applications are also obtained from solid solutions with zirconates. Doping with other ions for Ba (for example with rare earths) offers the semiconducting positive temperature coefficient of resistivity PTC thermistors and heaters.

Either as a ceramic discapacitor or a multi-layer capacitor (MLC), $BaTiO_3$ represents approximately 80%-90% of the world capacitor industry. According to world ceramic capacitor (1991), the current consumption of $BaTiO_3$ capacitors amounts to $170 million per year worldwide. This figure is expected to double in the next 10 years, and growth is expected not only in discrete capacitors but also in integrated packages which incorporate ceramic capacitors as well as other devices in a sintered ceramic monolith.

The research in the field of $BaTiO_3$-based materials has been a continuous research tradition in the NRC not only by solid state but also by wet chemical methods. Both dielectric and rare earth doped PTC semiconductor barium titanates have been prepared by oxalate coprecipitation techniques followed by pyrolysis (26,27). High purity, submicron, and unagglomerated powders, compared with the coarse agglomerated powders by the traditional methods, have been obtained. The sintering temperatures are 100°C to 200°C lower than conventionally prepared powders, with improved microstructural and electrical properties. An enhancement in the magnitude of the PTC resistivity anomaly has also been achieved. The lower sintering temperature means cost reduction. Furthermore, these powders promote the ability to fabricate electronic devices with higher package density.

A research plan will soon start in NRC labs to prepare a series of electronic materials by the low-temperature hydrothermal processes. It is hoped that even better powder characteristics will be obtained by these processes.

In the field of lead-based compounds, the sol-gel method has been adopted for the preparation of lead zirconate aiming for fine and homogeneous powders with uniform particle size distributions (28). Such methods are recommended for better densification properties, and for the elimination of the environmental and health concerns of lead compounds.

(b) *Zinc oxide varistors*

Zinc oxide varistors are novel electronic ceramic devices whose primary function is to sense and limit (i.e. clamp) transient voltage surges and to do so repeatedly without being destroyed. Their current-voltage characteristic is nonlinear, similar to that of a zener diode. But unlike a diode, ZnO varistors can limit overvoltage equally in both polarities, thus giving rise to a current-voltage characteristic which is analogous to two back-to-back diodes. They can be used over a wide range of voltage and currents. Their versatility has made varistors useful in both the power industry as well as in the semiconductor industry.

The growing demand for ZnO varistors results from the fact that their non-linear characteristic as well as the range of voltage and current over which the device can be used is far superior to those of SiC-based devices, the most popular non-linear resistor prior to the advent of the ZnO varistor. In the NRC, a joint research project is being carried out between the departments of solid state physics and ceramics to investigate the possible control of the crucial boundary layer of ZnO when prepared by non-conventional methods and using certain dopant oxides.

(c) *High-temperature ceramic superconductors*

Until five years ago it was taken for granted that superconducting transition temperatures were limited to 23°K. But with the discovery of lanthanum stronium cuperate, the temperature nearly doubled. It doubled again with the discovery of $Y Ba_2 Cu_3 O_7$, the so-called 1-2-3 compound. The research discoveries continued to offer the compound with a zero resistance at about 107°K, and the Th-Ba-Ca-Cu-O compound that pushed the zero-resistance point to 125°K. There have been many reports of high transition temperatures. So far, these results have been difficult to reproduce, and there is no consensus about their validity.

Unlike most earlier superconductors, the new materials are ceramics, so many techniques of ceramic processing have been applied to their synthesis. The new superconductors have already been prepared in the form of wires, thin films, tapes and single crystals, in addition to sintered granular material. Yet, many challenges remain; the ceramic or polycrystalline material suffers from low critical current densities, and the single crystals are still generally too small for decisive neutron-scattering studies, which would allow their magnetic correlations to be determined.

These new superconductors have opened up a large number of possible applications: frictionless generators, motors and high-speed trains; power transmission lines, nuclear accelerators and hydrogen fusion; and radiation detectors for astronomy. However, even the most optimistic experts suggest that these applications will take years to exploit.

In the ESCWA member countries, the application of high-temperature ceramic superconductors is far away from present technological capabilities. Even the good grasping of material preparation, processing, and forming into various shapes is not yet anticipated. However, scientists and technicians in ESCWA member countries should not wait while the developed world progresses decade after decade or even year after year.

In the NRC, there is research work on the preparation and characterization of Bi-based ceramic superconductors. In many Egyptian universities there are also scattered works on high-Tc superconductors. However, such efforts do not represent a national trend and cannot yield major achievements unless they are unified, especially since the funding in this research area is rather costly. The Council of Basic Sciences in the Egyptian Academy of Scientific Research and Technology is founding a committee of experts from Egyptian universities and NRC as well as some scientists from abroad to form a long-term plan for research and application on high-Tc superconductors in Egypt. Fortunately, the Academy promised to finance the plan with a sizable budget, so that a strong push can be started in that interesting field.

(d) *Solid electrolytes and sensors*

Interest in electronic ceramics in the NRC also covered the ceramic electrolytes suitable for fuel cells and solid batteries. Stabilized zirconia characterization and properties (29,30), as well as β-alumina preparation (31,32) and properties (33), substitution of other ions for sodium (34), and radiation effects (35) have been thoroughly studied.

Ceramic sensors are currently a matter of study. Titanates and zirconia are suitable for use as electronic and oxygen-gas sensors, respectively. Titania ceramics can be used as exhaust-gas oxygen sensors.

(c) *Bioceramics*

Materials that have been applied to surgical implants cover a broad spectrum. Among these are plastics, metals, rubber, textiles and ceramics. Acceptance or rejection usually hinges on a combination of needed properties such as tissue compatibility, enzymatic and hydrolytic stability, and chemical, physical and mechanical properties. Ceramics are a good example for a material that moved from being considered too brittle for most implant applications into the status of "material choice" for new and exciting uses. Its outstanding success has encouraged the medical/scientific community, which coined the term "bioceramics".

Bioceramics can be grouped into three classes: nearly inert, surface active, and reabsorbable. *In vitro* and *in vivo* investigations have centred around alumina, hydroxylapatite, calcium and trisodium phosphate, carbon, various composites and special glass compositions. Several successful load-bearing and non load-bearing applications fall within these groups. The most notable of these are artificial heart valves, knee and hip joint prostheses, alveolar ridge reconstructions, tooth/root implants, percutaneous access devices, bone implants and artificial tendons.

Because of the diversity that bioceramics possess, investigative activity is growing and commanding worldwide attention. These materials are being credited with solving medical device design problems that a few years ago were relegated to plastics and metals exclusively. Europe, Japan and the United States are nearly equal partners in their development of this vital area of materials.

In the NRC widespread research activities on bioceramics has been conducted on the three mentioned bioceramic materials, since the beginning of the 1980s. Most of the work is being done in the department of ceramics in cooperation with the faculties of medicine, dentistry, veterinary medicine, and engineering in Egyptian universities. They have aimed collectively at establishing a scientific knowledge base in this field for the possible emergence of a pilot plant and a production scale in biomaterials, and also to create multiskilled graduates in that field.

Both calcium phosphate and hydroxylapatite have been prepared by traditional and chemical coprecipitation techniques. The materials have been fully evaluated for their powder characteristics and sinterability at various temperatures. Also, porous alumina ceramics have been prepared by sintering at low temperatures. The three materials ceramics have been investigated for their physical and mechanical properties. The biocompatibility and histocompatibility of these bioceramics as well as their medical and dental application are a matter of continuous study.

G. Issues and recommendations for new and advanced materials technologies

From the preceding sections, it appears that quite a number of sophisticated materials are being dealt with from the research point of view in the NRC. More materials are also being examined in other R&D institutes and universities in Egypt. This shows that scientists in Egypt are aware of the importance of these materials and their implications for development.

However, the efforts that have been made are rather scattered or confined to the institutes to which the concerned individual scientists belong. No nationally oriented policy for new and advanced materials or technologies exists as yet in Egypt, and most probably in other ESCWA member countries.

Although materials science and technology has progressed rapidly in developed countries, it is important for ESCWA member countries to cope with this challenge in the world of today. This is not an impossible task. The Republic of Korea is an example. In thirty years it has made a miraculous transformation.

In the ESCWA member countries, there is an urgent need for a supreme committee for new and advanced materials technologies in each country. These committees should formulate long-term plans and establish databases that can provide the information needed for the plan and the committees. The committees should be composed of experts in production sectors, energy, natural resources, health and environment, together with scientists from R&D institutes and universities. Even bankers, consumers and sales representatives should be included in these committees so that all aspects of needs are considered in the plans.

The Academy of Scientific Research and Technology (ASRT) in Egypt is the most suitable scientific organization that can effectively play this role. The ASRT has made several studies in connection with many technologies in Egypt.

To achieve these objectives, the following recommendations should be taken into consideration:

1. An accurate survey of the specialists in new and advanced materials in the country should be made;

2. A parallel survey should be made of the instruments and measuring tools in the scientific institutions concerned;

3. Funding programmes should be undertaken to face the costly research work of advanced materials;

4. Priorities should be drawn within the field of materials, based on society's need and the availability of materials, skilled people, and manufacturing capabilities in the private and public sectors;

5. Marketing studies must be carried out for local and possible export measures, considering that new materials will not replace existing ones; rather they are a group of properties required by the user in specific applications;

6. Feasibility studies are essential for the current capabilities of existing factories and the possible establishment of small- and medium-sized firms for the manufacturing of advanced materials.

Some recommendations regarding the development of advanced materials technology in Egypt are presented below as a model for the other ESCWA member countries.

(a) *Education and training requirements*

In ESCWA member countries, the infrastructure of universities and other high educational institutions is still in the traditional frame of the European system. The universities are divided into faculties and the faculties into departments. Each department has its own separate identity and entity (for example, departments of chemistry, physics, biology, and mechanical, electrical and civil engineering). This is at a time when discoveries throughout the last quarter of this century have blurred the sharp borders between the different branches of science. The United States, Japan and some Western European countries have realized that the real revolution in materials technology cannot be realized unless interdisciplinary divisions are founded, and hence MSE departments are found throughout American universities. It is recognized that without multiskilled graduates we will not be able to enter the world of materials in a reasonable time. Such skills enable graduates to deal with composites and superalloys, for instance. Materials engineers can bridge the gap between research results and applications, a gap which is wide in the developed countries. Biomaterials engineers can also bridge the gap between biomaterials manufacturers and surgeons.

Important topics in the field of materials technology, such as ceramics, glass, polymers, fibres and alloys, are not included among the undergraduate courses in Egypt and most probably in other ESCWA member countries as well. It is strongly advised that the suggested MSE departments in the universities of the region should cover these topics in their regular curricula.

(b) *The role of research institutes*

Research scientists in developing countries in general and in ESCWA member countries specifically should take the leading role, at least for the time being, in the development of advanced materials in their countries. The nature of their work enables them to be aware of the latest advances in the developed world. Also, they are probably most aware of the positive implications of these materials for the economy. They can plan and conduct, in cooperation with experts in industry, R&D programmes up to the level of production in these fields. However, building up efficient materials science and technology divisions within the scientific institutes is a prerequisite. The capabilities of these divisions should be integrated to comprise the structure—synthesis/processing—properties performance continuity and its application in all classes of materials. This multidisciplinary approach needs an appropriate balance between pure scientific and applied research and the technological considerations. It also needs collective libraries, up-to-date instruments and highly skilled technicians. Recent MSE literature can be purchased. Young researchers can be sent abroad to acquire the skills which they lack. The high price of modern measuring instruments represents the major problem. The Government should provide assistance in this respect, and the assistance of international organizations is strongly recommended.

The work in the MSE divisions of the research institutes should be oriented to fulfil project objectives. Either the Government or the big industrial organizations must support long-term projects. The scientific and technological standards must be strengthened to enable these multidisciplinary institutions to make forecasts, to assess and to elucidate the national policies of materials and material-related technologies.

(c) *Advanced materials and industry*

So far, in the ESCWA member countries, industrial capabilities are structured to produce conventional products. For example, in the field of ceramics, many such products are produced by Egyptian factories. However, production of advanced ceramics has not yet begun. The restructuring and modernization needed for this industry to meet the demands of advanced materials production is a costly process. It must be made with great care and after several studies of market needs, capability to acquire and absorb new technologies, quality of product and cost of production, and competition with foreign products. For the time being, it is advisable that small or medium-sized firms, attached to the large companies, be established for the new products. These firms must be backed by the Government, and cooperation with research institutes in specific R&D programmes is essential in the early stages. Certain new products should be adopted and articulated so that strong competition from foreign companies will not represent a danger.

Among industry people, the degree of awareness of the importance of advanced materials must be strengthened. Also, foreign firms should be attached to form joint R&D and technology projects. This would be a good start to acquire sophisticated technology. For example, in black sand a chemical-ceramic-electronics company can be established to produce both zirconia and titania from zircon and rutile, respectively; fabricate both materials to the suitable electronic use for fuel cell and condenser applications; and make use of these components in electronic circuits. Both material powders can be used also in glass, glaze, refractories, paints, and other industries leading to reduction of imported products.

The establishment of a new plant for the production of high-quality alumina for special uses, attached to the Aluminium Factory in Nagaa Hamaadi in southern Egypt, represents a good turning point towards the economically useful integration of industry. In this respect, the establishment of another plant in the future for the production of fused alumina products is also recommended. These products are needed in other industries and for pilot plant and laboratory uses. The consumption of fused alumina in Egypt is expected to increase in the coming years.

The zirconia and titania mentioned earlier are good examples as well. Another example is connected with the industrially needed barium carbonate for glass, ceramic and building materials industries. Barium carbonate is obtained chemically from the mineral barite (barium sulfate). This mineral is imported; it is time to start using it industrially as a source for the carbonate.

Preparing multi-skilled graduates working in industry is essential for these kinds of industries. The partnership between industry and research institutes can be very helpful in this respect. Industry in the ESCWA region must become accustomed to financing long-term R&D programmes in institutes and universities; quick, short-term results should not always be the aim. In Japan and Germany, industry is financing more than 90% of the oriented research. Twenty years ago, a ceramic heat engine was a dream. Now, due to the good cooperation between research and industry in these countries, it is becoming a reality.

(d) *Policy options for new and advanced materials in Egypt as an example for other ESCWA member countries*

Although Egypt possesses a strong setup of Government and private institutions which deal with different aspects of materials, the country has not yet formulated a national strategy for new and advanced materials. It should do so without delay.

The expected national strategy should take into consideration the following points:

(a) The interests of all shareholders;

(b) The local economic and social conditions;

(c) The experiences of industrialized as well as newly industrialized and other developing countries.

An important element in this strategy is the integration of different institutions and activities in the field. This could be achieved by establishing a national materials council of the type proposed by L. Kaounides(5).

In addition to its integrating capacity, the proposed council should also formulate policies and monitor their implementation. Such a body would employ multidisciplinary teams with the ability to: monitor scientific and technological developments; assess their domestic economic implications; and formulate technological and research responses nationally and, in due course, regionally.

The council would need also to embrace private industry, universities, scientific societies and research laboratories in a national effort to develop an appropriate scientific, technological and industrial response to the changes ushered in by the materials and electronics revolutions. A key area that must be addressed is the unpredictability and large discontinuities that can result from major shocks and rapid technical change: if change cannot be predicted, then institutions and mechanisms must be built to effectively respond to change.

Another important element of the strategy should include establishing a multidisciplinary R&D facility for materials science and technology with very strong links with the industrial manufacturing sector. Plans to establish such an institute in Egypt within the framework of the newly planned Mubarak City for Science and Technology are in progress.

The Academy of Scientific Research and Technology should also sponsor a national R&D programme on new and advanced materials and establish the country's priorities in this field. Universities, research institutions and R&D units in the productive sector should contribute to this national R&D effort.

It is also imperative to formulate a national plan for training the needed manpower, especially at the university level. In this connection the possibility of establishing specialized departments for materials science and technology should be considered. The strengthening and updating of chemistry, physics and mathematics curricula with up-to-date information in materials science and technology is urgent.

The strategy should also devise programmes for cooperation with United Nations and other agencies, as well as bilateral programmes with developed and developing countries.

REFERENCES

1. N.M. Ghoneim, Production of High Frequency Electrical Ceramics, M.Sc thesis, Cairo University, August 1968.

2. A.A. El-Kolali and N.M. Ghoneim, Utilization of Egyptian Black Sands Rutile for the Manufacture of Titania Ceramic Dielectrics, Indian Ceramics, pp 657-661, Dec. 1979.

3. A.A. El-Kolali and N.M. Ghoneim, Electrical and Thermal Properties of Pure and Impure Barium Titanate, Ceramurgia, 7 (1) 13-17 (1977).

4. M.M. Abu-Sekkina, On the Sintering Behaviour of Zirconium Oxide, M.Sc. thesis, Cairo University, May 1969.

5. W.I. Abdel Fattah and A.T. Hussein, Alumina Ceramics, Recent Advances in Science and Technology of Materials, Part 2, 267-84, 1974; Editor, A. Bishay, Plenum Press.

6. N.M. Ghoneim and S.B. Hanna, Characterization of Yttria-Stabilized Zirconia Powders Prepared by High Temperature Hydrolysis, Ceramic Forum Int., 3/86, 96-99 (1986).

7. S.B. Hanna, N.M. Ghoneim, Characterization and Densification of Lanthana-Zirconia Powders Prepared by High Temperature Hydrolysis, J. Mat. Sci, 21, 3043-3049 (1986).

8. N.M. Ghoneim, S. Hanafi, and S.A. Abu El-Enein, Characteristics and Effect of Thermal Treatment on Surface Texture of Ultrafine Zirconia Powders, J. Mat. Sci, 22, 791-97 (1987).

9. N.M. Ghoneim and S.B. Hanna, Sintering and Microstructure of Ultrafine Yttria-Zirconia Compacts, J. Mat. Sci, 25, 5192-98 (1990).

10. S.B. Hanna, Studies on the Production of Zirconia from Egyptian Zircon, Ceramurgia, 10, 13 (1980).

11. M.M. Abu-Sekkina and S.B. Hanna, A Study of the Phase Reactions in the $CaSO_4$-$ZrSiO_4$ System, Sprechsaal, 115, 1022 (1982).

12. H.K. Imbaby, N.A. Mansour, S.B. Hanna and M.R. Kamel, Silicon Carbide and Nitride from Rice Hulls; I-impregnation of rice hulls in ferrous sulphate, Bull. NRC (Egypt), 5, 11, 1980.

13. N.A. Mansour, S.B. Hanna, A.S. Taha, and H.M. Abd-Allah, Production of Silicon Carbide from Rice Hulls, Technical Report No. 2, Refractories and Building Materials Department, National Research Centre, Dec. 1980.

14. G. Wotting and G. Ziegler; Powder Characteristics and Sintering Behaviour of Silicon Nitride Powders, Interceram, 35 (2) 32 - 35 (1986).

15. G. Grathwohl, S.B. Hanna and F. Thummler, Hot Pressing and Properties of Different Si_3N_4 Qualities, Trans. J. Brit Geram. Soc., 81, (1982).

16. S.B. Hanna, G. Grathwohl and F. Thummler, Oxidation Behaviour of Hot Pressed Silicon Nitride Containing Minor Amounts of Magnesia, Interceram, 32, 30 (1983).

17. M.M. Abu-Sekkina, S.B. Hanna, M.M. Goda and M.M. Rashad, Microstructural and Spectral Investigations of the Mechanism of Surface Layer Formation During the Oxidation of Hot-Pressed Si_3N_4 in Air at High Temperature, Surface Tech., 25, 77 (1985).

18. S.B. Hanna and F.F. Abd-El-Mohsen, Thermal Conversion of Si-Resin to High Stability Si_3N_4 and SiC infiltrated RSSN Material, Ceramurgia, 15, 22 (1985).

19. S.B. Hanna, and N.M. Ghoneim, Formation of Sialon from Kaolin and Rice Hulls, Interceram, 35, 42 (1986).

20. N.M. Ghoneim, Characterization of Electrical and Microstructural properties of Dielectric and Semiconductor Barium Titanates Prepared by Chemical Coprecipitation, Ph.D. thesis, Hungarian Academy of Science, Budapest, June 1976.

21. N.M. Ghoneim, S. Hanafi, and Th. Salem, Effect of Calcination on Characteristics, Surface Texture, and Sinterability of Chemically Prepared Barium Titanate, J. Mat. Sci., 25, 3241-3248 (1990).

22. D.M. Ibrahim and H.W. Hennicke, Preparation of Lead Zirconate by a Sol-Gel Method. Trans. J. Br. Ceram. Soc., 80 (8-12) 18-26 (1981).

23. N.M. Ghoneim and K. Abd El-Hadi, Electrical Properties of Stabilized Zirconia Ceramics, under publication.

24. N.M. Ghoneim, Range of Stabilization and Properties in Scandia-Stabilized Zirconia Ceramics Prepared by Hydrothermal Techniques, under publication.

25. M.Z. Mostafa, M. F. El-Shahat and M. Monshi, Preparation and Study of Different forms of Sodium Β-Alumina, Sci. Ceramics, 11, 105, 1981.

26. W.I. Abd-El-Fattah and M.Z. Mostafa, Formation and Stability of Na-Alumina, Z.Anorg. Allg. Chemi, 435, 292 (1974).

27. W.I. Abdel Fattah, A.A. El-Kholi, Production of Alumina Bodies and their Volume Resistivity, Sprechsaal, 6, 361-366 (1977).

28. W.I. Abdel Fattah, I.F. Huwaidy, M.A. Selim, Replacement of Sodium Ions in Alumina by Monovalent, Divalent and Trivalent Cations, Egypt, J. Chem., 2, 24, (1981).

29. M.A. Fadel, W.G. Osiris and W.I. Abdel Fattah, Fast Neutron Effects on Li - Alumina Ceramics, Radiation Effects Express, 2, 109-13 (1988).

30. United Nations Industrial Development Organization, Expert Group Meeting on Prospects for Industrialization Policies in Developing Countries, Vienna, Austria, April 1989, Technology Case Study No. 5, by L. Kaounides.

Other references

1. S. Das and T.R. Curlee, Advanced Materials Information Needs: A survey Report, Am. Cer. Soc. Bull., 70 (2) 234 - 239 (1991).

2. T.R. Curlee and D.A. Trumble, Advanced Materials: Information and Analysis Needs, Tech. Rept. ORNL/TN-11593, Oak-Ridge National Lab., Oak Ridge, TN, Sept. 87 pp. 1990.

3. A.R.C. Westwood and J.P. Skalny, Advanced ceramics: Opportunity and Challenge, Adv. Cer. Mat., 1 (1) 21-25 (1986).

4. L.M. Shepperd, Cost-Effective Manufacturing of Advanced Ceramics, Am. Cer. Soc. Bull., 70 (40) 692-701 (1991).

5. Fine Ceramics-Annual Report for Overseas Readers, Japan Fine Ceramics Assn., Tokyo, Japan, March 1985; p. 6.

6. J.I. Muller, Handicaping the World's Derby for Advanced Ceramics, Am. Cer. Soc. Bull., 61 (5) 588-590 (1982).

Discussion of Part Three, Paper One

Mr. Lakis Kaounides:

Q. As far as I can see, materials science and engineering has been applied very successfully in Malaysia in defending natural rubber against synthetic rubber. In some applications, natural rubber has become so good that it has precluded the inroads in specific implications by synthetic rubber. At the same time, Malaysia has moved to higher value-added production.

It is through the applications of the scientific capabilities domestically within Malaysia that this has been possible and they have been able to move at that stage and also address social needs and export, of course. That is just to inject a note of optimism.

Ans. I was not optimistic that new materials would solve all problems. But still we have to think: what kind of challenges and in which fields? Unless new materials contribute to meet the challenges of the basic needs in the developing countries, I think they will have no chance in our countries.

Mr. R.S. Ganapathy:

Q. I want to give an example from India to endorse Mr. Kaounides' point. You mentioned the problem of housing. We have an acute housing shortage, and the gap is actually increasing. In the last 10 years, a solution was offered for developing low-cost building materials using mud blocks. This was actually inspired by the famous Egyptian architect, Hassan Fathy, and based on his work. There is a famous British architect who lived in India for many years, Larry Baker, who has developed low-cost housing material, bricks and mud blocks. Actually, two- or three-storey buildings have been built in India using mud blocks, and they cost about one third what conventional housing material costs. I wanted to mention that as an example of an indigenous building material developed which addresses a basic need.

Paper Two

NEW MATERIALS AND TECHNOLOGIES IN JORDAN

Falak Al-Sarraf

Abstract

Jordan has developed some basic engineering materials related to all known categories, namely polymers, metals, ceramics and minerals. These materials include plastics, ceramicware, cement, concrete, glass, iron and steel, aluminium, copper, potash and phosphate. Raw materials used for the ceramics industries are mostly local; good-quality clays, limestone, glass sand, gypsum, feldspar and concrete aggregates are widely available in Jordan. The technology employed is well developed, a good combination of traditional methods and transferred technology have been applied.

The potash and phosphate fertilizers industries are in a well-developed state; they are well established, highly mechanized and with a higher technology content. This is largely due to successive government development plans that emphasized agricultural-related industries. The driving force has been the abundant natural resources: phosphate rocks and the Dead Sea.

On the other hand, plastics industries in Jordan depend entirely on imported raw materials. Thus, the technologies involved are restricted to processing, excluding polymerization. Metallics industries also face obstacles related to the large expenditures needed to exploit, beneficiate and process the metallic minerals available in the country. Moreover, these industries need high technologies Jordan lacks. They also need energy and Jordan lacks domestic energy resources that can be commercially utilized through traditional technologies.

Jordan has been more successful in developing and producing ceramics and minerals, due to the abundance of non-metallic minerals, than polymers or metals requiring raw materials (natural or synthetic) that are not available. The major concern of Jordan has been the establishment of the basic infrastructure of economic development in terms of basic industries, highways, major townships massive irrigation projects, airports, bridges and so on. Such large-scale construction programmes involving application of sophisticated construction techniques have necessitated the use of sophisticated building materials such as cement ceramics, structural steel and glass. These were initially imported, but production capacities were later developed in varying aspects to produce them locally.

As a developing country, Jordan has reached an acceptable stage in building the local capacity necessary for the development of materials. This includes: provision of adequate infrastructural facilities for research and development; provision of education and training of personnel to deal with problems associated with materials development; establishing national standards and quality-control programmes, and accessibility to scientific and technological information.

This paper recommends establishing a material science and technology centre; strengthening the links between universities, research centres and Government; supporting testing and quality-control institutions; employing technology transfer; revitalization of science and technology; and increasing regional and international cooperation.

Introduction

Materials science and technology is a multidisciplinary activity dealing with the generation and application of knowledge relating to the composition, structure and processing of materials to obtain the required properties.

All materials have certain properties which determine their use. Plastics and other organic materials are light weight, workable and insulative. However, their thermal resistance and strength restrict their use. Glass and other inorganic materials are hard and thermal and corrosion resistant. Uses of these materials are restricted owing to their unworkability and brittleness. Steel and other metals are high in strength, workability and electric conductivity. Nevertheless, these materials are often inferior to other non-metal materials in terms of corrosion resistance, relative strength and thermal resistance.

A. MATERIALS CLASSIFICATION

According to their structures and structure-property, materials are classified into:

(a) Polymers: These are "organic materials" consisting mainly of carbon, and their common feature is their covalent bond. Polymers include plastics, wood, natural and synthetic rubber, nylon, etc..

(b) Metals: These are "inorganic materials" with a metal bond. These materials cover iron and iron-based alloys (steel and stainless steel), aluminium, and other ferrous and non-ferrous materials;

(c) Ceramics: These are "inorganic materials" with ionic and covalent bond. Besides traditional ceramics—products based on the clay and pottery industry—the term ceramics covers refractories, cement, glass and new ceramics, which are pure single oxides, carbides and nitrides.

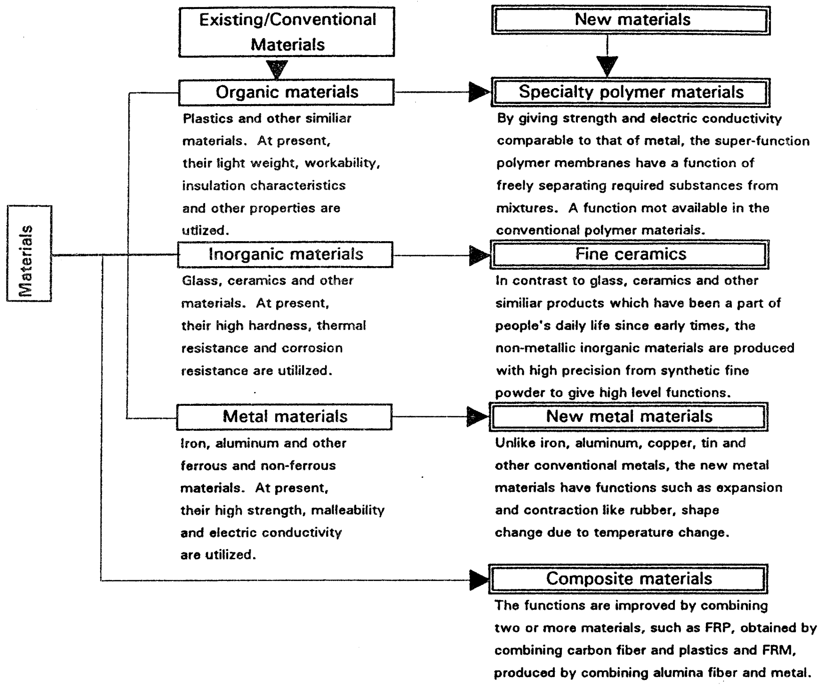
In addition to polymers, metals and ceramics, there are the advanced composite materials which consist of a combination of any of them. Figure I shows an overall schematic diagram of new materials those with a high research and development cost component.

With respect to application, various raw materials are transformed into engineering materials in order to fulfil specific engineering needs and requirements. The main engineering materials are:

(a) Structural materials (that is, materials showing interesting mechanical properties) include metals, ceramics, polymers and composites;

(b) Functional materials (that is, those meeting unique specifications for one or more non-mechanical properties needed for a specific function such as electrical, magnetic or optical) include electronic devices, photonics, photovoltaics and sensors, electromechanical, superconductors, and magnetic materials;

Figure I. OVERALL SCHEMATIC DIAGRAM OF NEW MATERIALS



Source: Centre for Science and Technology for Development, *Bulletin of the Advanced Technology Alert System*, "Materials technology and development," New York, Issue No. 5, May 1988, United Nations Publication, Sales No. E.87.II.A.2.

(c) Civil engineering materials (that is, construction materials such as cement, concrete, plaster, admixtures, etc., used for buildings, housing, roads and bridges);

(d) Renewable materials (that is, recycling materials such as wood, waste paper and straw).

Materials covered in this paper will be categorized according to the first classification, that is polymers, metals and ceramics. Composite materials will be included within these categories wherever relevant. This also means—if the second classification is considered—that structural materials and most civil engineering materials will be covered.

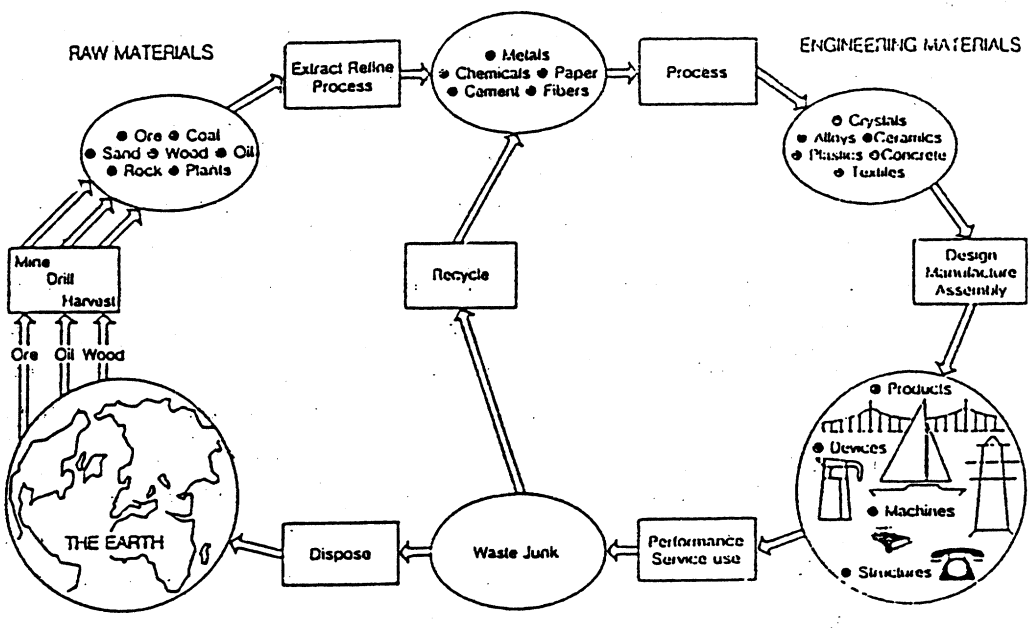
In each of these categories there have been technological developments regarding material composition and/or processing that have resulted in new products, that is, new metals substituting for existing metals, new ceramics substituting for existing ceramics, and so on. The most important changes, however, are in the substitution of one type of material for another, such as ceramics and polymers for metals.

Structural materials, which comprise most of this paper, are often the more conventional materials. In one meaning, conventional materials can be considered as advanced materials if as a result of research and development they attain improved characteristics or performance in service. Usually, the benefit gained through the improvement of existing materials is as much as that provided by the invention of completely new materials.

B. MATERIALS CYCLE

All materials used in the construction of machines, devices, habitation and other everyday necessities of man move in cycles. Raw materials such as ores, hydrocarbons and wood from the earth, or oxygen, nitrogen and other gases from the atmosphere are converted into simple metals, chemicals and other basic materials through refining and purifying processes. These basic materials in turn are modified into alloys, ceramics, polymers, composites or other engineering materials for processing into products; the products are transformed into waste by service use and ageing. Through recycling or disposal, the waste materials are eventually returned to the earth, water or atmosphere but in a quite different shape and composition (figure II).

Figure II. The total materials cycle: overview



Source: Centre for Science and Technology for Development, *Bulletin of the Advanced Technology Alert System*, "Materials technology and development," New York, Issue No. 5, May 1988, United Nations Publication, Sales No. E.87.II.A.2.

All "materials cycles" are interconnected by "energy cycles", since energy is needed in exploration, processing, production and use or recycling. Energy production again utilizes the earth's resources (coal, oil, uranium, oxygen water, etc.) so that "the total materials cycle" also includes all materials for producing energy. "Therefore, the main task of engineers is to establish processes with minimized dissipation of materials and energy by fulfilling the technical and economic demands of industry" (1).[1]

C. Development of a new material

Several aspects must be taken into account in the development of a new material or product. These are illustrated in the schematic flow-sheet shown in figure III, starting with raw materials and ending with the new material or product. Assuming that the necessary scientific equipment and general infrastructure are provided, the research and development structure (RDS) constitutes a necessary interphase for any economic or political decision to be undertaken by a particular Government or company. RDS implies a multidisciplinary research and development structure, since advances in new materials need to be dealt with by a group of specialists in different disciplines.

This RDS could be realized through an institute of materials science and technology having the following objectives: to evolve a national materials policy based on technological forecasting and assessment; to utilize local materials; to develop new materials; to test for quality control; and to develop a capability to participate in the evolution of international materials policy.

D. Materials technology and developing countries

In most developing countries, materials technology evolved from the use of agricultural materials, stone, bronze, iron, clays and ceramics. However, most developing countries have not had the full benefit of the scientific and industrial revolutions of the past 300 years. This has resulted in the lack of applicability of materials technology in developing countries, both in quality and quantity, compared to the situation in advanced countries.

The current average availability of manufactured materials and energy per capita in the developing countries is often 100 times less than in the advanced countries. Moreover, the cost of materials in relation to income in developing countries is very high, causing further unequal distributions of materials. An abundant supply of materials at low cost associated with fair distribution would help reduce human suffering in the developing world and lessen local, national and international conflicts. The link between materials and basic human needs is much more important than that between materials and weapon systems, for example.

The challenge for development of materials for at least the next 50 years will be to increase the availability of materials required for housing, water, food, energy and health care by as much as 10 to 100 times without pressing too much on resources, energy, environment and employment. The population of developing countries will be more than doubled in 50 years, and at that time these countries will be trying to attain the standards available in the

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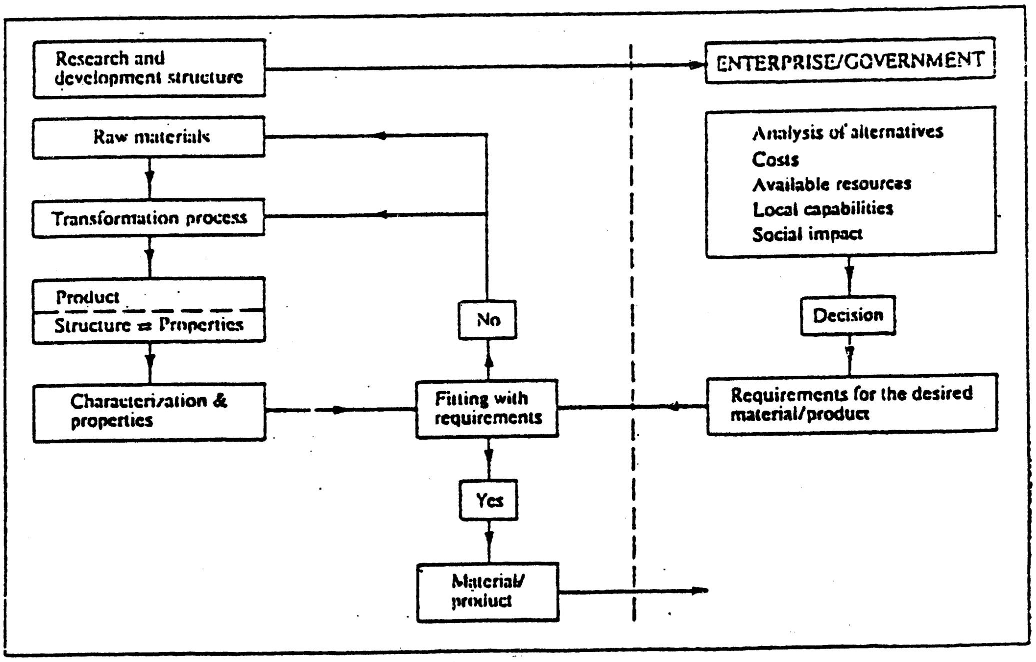
[1] For the list of references, see page 428 *f.*

Figure III. FLOW SHEET FOR THE DEVELOPMENT OF NEW MATERIAL OR PRODUCT



Source: Centre for Science and Technology for Development, *Bulletin of the Advanced Technology Alert System*, "Materials technology and development," New York, Issue No. 5, May 1988, United Nations Publication, Sales No. E.87.II.A.2.

advanced countries today. To meet this challenge, basic advances in science should be developed in a standard, systemized way, and accelerated in time by growing input. Otherwise, the less developed of the developing countries will continue to lag behind economically.

E. MATERIALS IN JORDAN

Most of the developments achieved in materials technology in Jordan are limited to the sectors concerned with basic commodities.

Generally, Jordan has developed those basic materials which are mentioned in the materials cycle (figure II) rather than engineering or new sophisticated materials.

This paper highlights the new materials and technologies developed, produced and adopted by; the manufacturing sector in Jordan (table 1). It would be difficult to cover all industries; reasonable number are covered throughout the following paragraphs, including their raw materials, state of the art, production rates, and technical and economic aspects. They are categorized under four main sections: polymers, metals, ceramics and minerals.

F. POLYMERS

(a) *Polymers in Jordan*

The plastics industry in Jordan has seen marked growth in the last two decades. The number of plastics manufacturers increased from 18 in 1973 to around 93 in 1990. The local plastics industry covers most conventional non-engineering consumer products. The basic technology is therefore established; basic materials and processing technology has been formed.

The major plastics items produced locally and the corresponding number of manufacturers are shown in the first part of table 1.

1. *Processing techniques of plastics*

Processing of plastics is principally carried out in three stages;

(a) Melting or softening of plastic material by heat;
(b) Forming the material into the required shape through dies and moulds;
(c) Solidification of the shaped material by cooling.

Local industry utilizes the following techniques for processing plastics:

(a) Extrusion of films, pipes, ropes, profiles and bags. This technique is widely used in Jordan owing to the ease of operation of the machines in comparison with other processing machines;

(b) Injection moulding of toys, houseware products, office items, etc. Although this method covers a wide variety of products and sizes, it is less common than extrusion owing to its more sophisticated machinery and control, which require well-trained labour. The machines also require moulds which are not available locally. The cost of imported moulds is very high making this type of production uneconomically;

(c) Foaming of specific thermosets for the production of artificial sponge and thermal insulation panels. The available machines cover the needs of the local market;

(d) Extrusion blow moulding of drums and containers of different sizes. The bottle stoppers are mostly imported;

(e) Compounding of powdered polymers and additives into granular form;

(f) Thermoforming of containers for juices and diary products utilizing semi-finished polymers;

(g) Compression moulding of thermosetting resins (less common);

(h) Fabrication of reinforced thermosetting resins by spraying or hand moulding.

Table 1. SELECTED MATERIALS AND PRODUCTS PRODUCED IN JORDAN

Materials		Products	Number of factories
Polymers		Pipes and hoses for water, electricity and gas.	30
		Shopping, general purpose and waste bags.	30
		Houseware products and food containers.	20
		Artificial sponge, thermal insulation panels, foamed boxes.	13
		Profiles, doors, windows, shutters, water tanks, furniture.	8
		Agricultural films.	5
Metals	Iron and Steel	Steel bars for concrete reinforcement.	3
		Steel billets.	1
		Steel pipes.	2
		Canning.	10
		Foundry.	37
		Moulds.	-
	Aluminium	Recycling scrap; ingots, blooms.	1
		Aluminium profiles.	1
	Copper	Rods, sections, taps, valves.	2

2. *Raw materials for the local plastics industry*

The raw materials for this sector are mostly imported since polymers are petroleum-based resins. The cost of raw materials amounts to 73% of the total production cost of plastics. In 1990, the equivalent of approximately 41 million Jordanian dinars (JD) was spent on imported raw materials for the plastics industry in comparison with JD 19 million on imported finished plastics products. This amounts to total plastics imports of around JD 59.57 million, or about 3.5% of Jordan's total imports. The last figure should be treated with caution, however, since plastics are also imported as components of other products such as automobiles and other transportation means, aeroplanes, mechanical and electrical machinery, audio and visual broadcasting and recording instruments, medical supplies, toys and recreational products, etc.

Table 1. (*continued*)

Materials		Products	Number of factories
Ceramics	Ceramicware	Clay bricks and blocks.	4
		Quarry tiles, hollow structural tiles.	4
		Sewer pipes.	3
		Ceramic tiles.	3
		Sanitary ware.	1
		Art ware.	1
	Glass	Sheet glass.	1
	Cement	Portland cement: ordinary, pozzolana, sulphate-resistant, white.	3
	Concrete	Forecast concrete.	1
		Ready-mixed concrete.	4
		Ready-mixed mortar.	2
		Concrete bricks and blocks.	1200
		Terrazo tiles.	300
		Draining and sewer pipes.	10
		Kerbstone.	10
Minerals	Potash	Potash fertilizers.	1
	Phosphate	Phosphoric acid, ammonium phosphate, aluminium fluoride.	1

The actual value of plastics imports could be as much as 10% of total imports as a result.

Around 52% of plastics raw materials are imported from the Arab countries, 37% from Europe and 5% from the Far East. It was difficult to obtain data on the import of specific raw materials owing to the way that published statistical break down the classification of raw materials. However, on the basis of local production, the major raw materials used in Jordan are:

(a) Polyvinyl chloride for pipe and profile production;

(b) Low- and high-density polyethylene for packaging, agriculture and pipes;

(c) Polypropylene for housewares, pipes, hoses, shoe heals and others;

(d) Polyurethane for furniture and thermal insulation;

(e) Polystyrene for thermal insulation, food containers and vegetables and fruit boxes for transport;

(f) Polyester resins for reinforced products;

(g) Other condensation resins for sanitary products and dinnerware.

All the above materials are classified as standard non-engineering plastics.

3. *Obstacles facing the plastics industry*

The main problems facing the local industry can be classified as technical or economic:

(a) Lack of knowledge and education on plastics, particularly on the structure/property/processing interaction;

(b) Lack of on-line quality control which aims at reducing defective products and optimizing accepted products to the standards of regional and international competition;

(c) Failure to employ research and development as a tool to upgrade the quality of existing materials, and to develop new products;

(d) Ineffective cooperation with the scientific institutions available in Jordan;

(e) Absence of moulds, dies and computer-aided design.

(f) Shortage of spare parts for processing machines owing to the fact that all processing machines are imported;

(g) Shortage of data banks, publications and technical studies;

(h) Absence of certain processing techniques that are vital to the advancement of materials and expansion of applications such as multilayer extrusion and moulding.

(b) *Economic problems*

(i) The existence of manufacturers of similar products, which does not allow the full utilization of production line capacity (around 60% of the full line capacity);

(ii) The nature of the plastic items produced locally—that is, mainly non-engineering consumer products—which do not contribute to the development of new industries such as engineering and assembly industries;

(iii) Lack of administrative studies in the planning stages; this is reflected in less than suitable choices regarding location, machinery, product type and quantity, storage arrangements, etc.;

(iv) The cost of imported raw materials, amounting to around 75% of the production cost;

(v) The absence of coordination both among the plastics companies themselves, and between the plastics industry in Jordan as a whole and that in the neighbouring countries, which affects exports pattern.

(c) *New horizons for the plastics industry in Jordan*

As far as polymers are concerned, there is a great potential for advances in the local plastics industry within the scope of the planned national policy. The following are several possibilities for expanding the local plastics industry:

1. *Utilization of waste plastics*

The use of recycled plastic waste offers a new era of plastics application. Plastic wastes have three main sources:

(a) End-user waste;
(b) In-plant waste;
(c) Low-value by-products from the petroleum or chemical industry.

Utilization of recycled waste would have various technical, economic, environmental and even social impacts. Technically, the deteriorated properties and status of waste materials dictate expansion of existing processing lines to allow for washing, drying, shredding, granulating and compounding the waste plastic prior to shaping. In specific applications, new processing techniques have to be adapted in order to avoid direct contact of the incorporated waste with the surroundings. A technical advantage of using waste in that manufacturers look for recyclable materials and for that manufacturers look for recyclable materials and for virgin materials with upgraded properties. The widest application of wastes is in the construction sector. Cement with aggregates, for example, offers a low-weight product with better wear resistance and ductility. Panels, sidings, roofings and floorings are other applications for recycled waste.

From an economics point of view, the additional steps in the processing of waste plastics such as collection, washing, grinding, etc., open new employment opportunities in the plastics industry. Also, the utilization of waste as a raw material would ultimately reduce imports of raw materials and save badly needed foreign currency.

Socially, when waste recycling is well established, the in-house practices of discarding waste could also be influenced.

2. *Multilayer technology*

Multilayer packages and containers could be tailored to the very specific requirements of the material to be packaged. Medical packaging, for example, requires exceptional barrier properties, sterilization resistance and mechanical strength. Food packaging demands superior gas barrier and aroma retention. The adaptation of this advanced technology requires:

(a) Knowledge of the physical properties of single materials and the adherence or compatibility of different selective materials. Analytical testing of the performance of the different combinations of materials is also needed;

(b) Insertion of other processing equipment working in harmony with the existing single-layer line;

(c) Modification of the die and mould design.

Multilayer technology, when successfully implemented, would fulfil local needs for efficient packaging of food, medicine and other technical goods, and it is therefore expected to have an influence on the imports of finished products owing to the complete absence of this technology in Jordan at the present time.

3. *Production of engineering parts and accessories*

Producing engineering parts and accessories would be the foundation stone for enhancing the assembly industry. Examples include the production of assembly parts for refrigerators, washing machines, televisions and electrical appliances, and the production of automobile parts such as lampheads, car bumpers, mirror housings, door and window handles, battery boxes, etc. The economic impact adding of this sector would naturally create new industries and employment opportunities. It would also be the seed of technical advances towards engineering industries.

4. *Production of non-conventional greenhouse covers*

The existing greenhouse covers used in Jordan are solely single-layer covers with thicknesses ranging from 180 to 200 microns, and they usually serve for two or three agricultural seasons. Non-conventional covers include long-life films, special purpose films (antifog, antifrost, thermal barrier, etc.), very thin films and multi-layer covers. All these modifications aim at reducing imports of raw materials for agricultural purposes as well as enhancing crop yield and protecting crops against different environmental effects. the ultimate goal is of course to supply the agricultural sector with the products it needs in the most economical way.

(d) *Future strategy for polymers in Jordan*

New horizons in medicine, housing, transportation, agriculture and even luxury items are discovered. The establishment of polymer research activities in the country and in the region is therefore a necessity dictated by technical advances achieved and by economic and environmental concerns.

The national development plan of Jordan has responded to the requirements of the industrial sector by focusing on the following elements:

(a) The establishment of new transfer industries, and expansion of existing industries, to substitute imported consumer products;

(b) Achieving integration between the industrial and other economic sectors such as agriculture and construction;

(c) Investigations and studies on local raw materials;

(d) Reduction of imports;

(e) Environmental protection;

(f) Industrial coordination with Arab countries.

The Jordanian Government has paid special attention to Jordan's leading research institute, the Royal Scientific Society (RSS), which provides technical consultation and services to the public and private sectors, and conduct applied scientific R&D related to local needs. Among the facilities of the RSS is the Plastics and Rubber Laboratory. During the past three years, the laboratory has been investigating the utilization of recycled plastic waste for the production of agricultural films. This ongoing research sets an example of regional and international cooperation. The research, supported by the International Development Research Centre (IDRC)/Canada, is a cooperative venture between the RSS in Jordan and McGill University in Canada. The exchange of experience and scientific knowledge has made possible the success of the project and the development of know-how that will be shared with local industry to ultimately benefit the farming community. Additionally, the know-how developed through this research be transferred and adapted to suit the specific technical and environmental requirements of Egypt in another collaborative work.

G. CERAMICS

(a) *Ceramic ware*

1. *Raw materials*

(i) *Clay*

Natural clay is the principal raw material for the ceramics industry. Clay is common in Jordan, and reserves of good-quality kaolinitic clays have been established. Clay deposits in Jordan are located in Mahis, Glor Kabid, Al-Aarda, Baqa'a, and Al-Azraq basin.

The most significant high-quality clay deposits in Jordan are found at Mahis, a village 20 kilometres north-west of Amman. The main constituent of Mahis clays is kaolinite, and it is found in two layers. The upper high-quality layer contains classes A and B with 1.5 million tonnes of reserves, and the lower layer contains class C with 0.5 million tonnes of reserves. Classes A and B are suitable for wall tiles and sanitaryware production, and are more suitable if beneficiated or blended with high-grade imported clay. Class C is suitable for heavy ceramics such as bricks, quarry tiles and pipes. Smaller reserves of clays are found at Ghor Kabid, Al-Aarda and Baqa'a areas. Clays of Ghor Kabid are of high quality and mineralogically resemble Mahis clays, but the AL_2O_3 contents are higher. Al-Azraq basin contains around 10 million tonnes of montmorillonite clays. The Rashadiya and Fujij areas have 10 million and 20 million tonnes of clay deposits, respectively, and the Baten El-Ghoul area in southern Jordan contains abundant reserves of sandy and silty clays, reaching 400 million tonnes.

This wide distribution and variety of clay deposits in Jordan means clays are available and suitable for almost most ceramics industries. The high-quality kaolinitic Mahis clays are suitable, once beneficiated or blended, for wall tiles and sanitaryware, while Al-Aarda, Baqa'a, and Baten El-Ghoul clays are suitable for clay bricks, floor quarries, roofing tiles, and sewer pipes. Ghor Kabid clays can be used for wall tiles, but they are most suitable for fireclay refractory bricks owing to the high proportion of contained alumina.

(ii) *Feldspar*

Medium-grade feldspars with a total alkali content ($K_2O + Na_2O$) of around 9% are found near Aqaba in Jabal Al-Ghoufran in Wadi Yutum, and in the Wadi Mahlaba area, with estimated reserves of 600,000 and 360,000 tonnes, respectively. To produce marketable feldspar suitable for the ceramics and glass industries, raw materials require beneficiation.

(iii) *Glass sand*

Glass sand is mainly used to produce glass and ceramics unlimited reserves of pure quartz sand exist in Jordan. These meet the specifications for glass sands, without or after simple upgrading processes, depending upon which grade of glass-sand quality is required. The main deposits are located in southern Jordan in Ras en-Naqab, Qa'Disi, Wadi Es Sik, and Petra area, with total proven reserves of around 15 million tonnes, and virtually unlimited indicated reserves.

2. *Clay bricks*

At present, Jordan has a small brick-making industry concentrated in the Amman area. The industry is developed and mechanized, and makes use of the full range of high-technology equipment required for clay preparation, shaping, drying and firing. There are four brick factories in Jordan producing extruded wirecut bricks, all with oil-fired kilns. Three plants have periodic kilns, and one has a continuous Hoffman kiln. The production rate of these factories is not regular but is subject rather to seasonal conditions and variations in market demand. Total annual local production is around 4,000 tonnes. All types of clay bricks produced, including solid, hollow and perforated. All four factories use Al-Aarda and Mahis (class C) clays. No imported material is required for this industry.

Although the clay brick industry in Jordan is mechanized and well developed, bricks are not widely used as a construction building material. Their usage is restricted to chimneys, bakeries and decorative works. This is largely due to direct competition with traditional building materials—mainly natural stone and concrete bricks—regarding cost and local building patterns and regulations.

3. *Quarry tiles, pipes and roofing tiles*

Other structural clay products besides clay bricks are also produced locally in Jordan. Such products include hollow blocks, hollow structural tiles, quarry tiles, sewer pipes and fittings, and roofing tiles. These products are produced by the same factories that produce clay bricks. The production rate of these products is not regular: in some cases they are produced upon request for a certain project. These products are consumed locally by the construction sector. hollow structural tiles are used for decorative works, and quarry tiles are used for flooring outdoor yards and sidewalks.

The use of clay pipes and fittings in Jordan is limited compared to concrete pipes, although the former are glazed and have better chemical resistance to sewage water. This is largely due to the fact that clay pipes are produced in a smaller range of diameters and cost more than concrete pipes. Moreover, plastic (PVC) pipes compete well with the small-diameter clay pipes used for internal drainage systems.

The roofing tile industry in Jordan is not well developed; the produced tiles are neither glazed nor vitrified, and subsequently their consumption is virtually non-existent compared to that of imported tiles. There were 1,658,109 kilograms of roofing tiles imported in 1990, having a value of JD 220,582.

Most of the above mentioned structural clay products are produced locally using natural clays from Al-Aarda and Mahis deposits.

4. *Ceramic tiles, sanitaryware and artware*

In 1976, a factory to produce ceramic tiles was set up in Jordan. In 1990, another factory started production.

Jordan Ceramics Industries Company (JCIC) produces ceramic wall and floor tiles. The industry is well developed and mechanized. Semi-dry pressed tiles are produced and fired (one firing process) using an oil-fired tunnel kiln. The factory produces a wide variety of glazed tiles: gloss and matt, white and coloured, plain and ornamented. JCIC produces around 1 million square meters a year (1,202,612 square metres in 1990, dropping to 930,181 square meters 1991. The tile body is produced completely from local raw materials. Clays from Mahis (no. 4) and Baten El-Ghoul deposits are used in addition to granite from Aqaba, sand from Ras en-Naqab, and limestone from the Amman area. On the other hand, the glaze material is mostly imported (90% imported frit material and 10% Ras en-Naqab sand). The glazing cost accounts for 35% the production cost.

The second ceramic tile factory, Arab Ceramics Industrial Company (ACICO), annually produces around 1 million square metres (full capacity is 1.85 million square metres), most of it consumed locally. Around 10% is exported (Saudi Arabia, Sudan, Russia). ACICO produces wall and floor tiles, at a production rate amounting to 75% of its full capacity. Semi-dry press tiles are produced, glazed, and single-fired in a tunnel kiln. All raw materials used for the body are local, while those used for the glaze are imported.

Another two factories have started preliminary trials to produce ceramic tiles, with one of them importing the tiles shaped and ready for glazing and firing.

The production of sanitaryware in Jordan is another technological development in the ceramics industry. Sanitaryware and sanitaryware appliances have been produced by JCIC since 1977, using the slip casting method for the body and spraying process for glaze coating. Raw materials employed to produce the body are a combination of local materials (kaolin from Mahis/No. 1 and Ras en-Naqab sand), and imported materials (China clay and ball clay from the United Kingdom and feldspar from Turkey). Materials used for the glaze layer are mostly imported (around 65%) including zirconium silicate, barium carbonate, talc, zinc oxide and feldspar. Local materials used for the glaze are sand and limestone.

The factory produces sinks, wash basins, shower trays, closets, bathroom traps, urinals and cisterns. The annual production of sanitaryware slightly exceeds the fully capacity, which is 2,000 tonnes. A second line of production with another 2,000 tonnes of capacity started production in 1992. Most of the production is consumed in Jordan, with only 5% being exported to neighbouring countries.

Artware has been produced in Jordan since 1989 by JCIC. The body and glaze are very similar to those of sanitaryware. This production line is continuously under development, with new designs and models being introduced. Annual production is around $165,000.

As of this writing, dinnerware is scheduled to be commercially produced as of 1993, as JCIC has started preliminary production.

(a) *Glass*

The glass industry in Jordan started with one or two small-scale glass-making factories based on recycling used glass products rather than producing glass from raw materials. These factories formerly remelted collected broken glass (all types of glass, including white or coloured, sheet, bottle or optical glass) using oil-fired furnaces, and shaped it with simple blowing or moulding techniques to produce household articles.

In 1984, however, the industry became fully advanced and mechanized when a large-scale sheet-glass factory started production. The Jordan Glass Industries Company (JCIC) produces soda-lime sheet glass by the drawing method. The technology employed is called "Pittsburg". The production process is continuous—24 hours a day for seven to nine years. Another production cycle (seven to nine years) will start once furnace maintenance is carried out. JGIC recently introduced a new technology to extend the working age of the furnace to 12 years by internally injecting the refractory bricks of the furnace while it is on.

In 1987, the factory started producing coloured glass instead of only white, and it is the only factory in the Arab world producing coloured glass with thicknesses of 4, 5, 6 and 8 millimetres.

The following materials are used by the glass factory:

(a) Glass sand: from Ras en-Naqab mentioned above.

(b) Dolomite: from Ain Ghazal quarries near Amman, at a distance of 280 kilometres from the factory. Recently a new location closer to the factory (Ras en-Naqab and Ash-Shadiya areas) was suggested for economic efficiency;

(c) Feldspar: formerly imported from Finland. In 1988 the factory started using Jordanian feldspar, as a result of extensive research performed jointly by NRA/MENR, the RSS, and two similar European glass factories. The use of local feldspar reduced by 90% the cost of this raw materials;

(d) Sodium sulphate: imported from France;

(e) Sodium carbonate: imported from France.

The local market consumes around 25% production, and the rest is exported to Arab countries including Egypt, Iraq, the Syrian Arab Republic, Yemen, Sudan, Saudi Arabia, Tunisia and Morocco.

Factory production for the years 1988, 1989 and 1990 was 17,235, 15,491 and 9,392 tonnes, respectively. The sudden production drop during 1990 was largely due to the Gulf war. The factory is considering exporting cullet glass that is, pieces of glass broken while manufacturing to Europe and the Far East.

Two new glass products are now under consideration by JGIC—bottle glass and fibre-glass. Although the two products require raw materials similar to those of sheet glass, which are available, nevertheless the production technology differs, and the marketing feasibility has to be studied carefully.

(b) *Refractories*

In present-day usage, ceramic products are understood to comprise all refractory materials. Refractories are non-metallic materials suitable for use at high temperatures in furnace construction.

The refractories of greatest commercial importance can be divided into several main groups. These are known as fire-clay, high-alumina, silica, basic and insulating refractories, with each group including a number of classes. In addition there are various special refractories including graphite, carbon, silicon carbide, fused alumina-silica, and others. They are made from many widely different raw materials, of which fire clay and quartzite are used in the largest quantities. Other raw materials include magnesite, chrome ore, diaspore, bauxite, zircon, olivine, dolomite, quartz and sandstone.

Refractory bricks in Jordan are being used to construct furnaces required for production processes at a number of large industries. these include phosphate, cement, gypsum, lime, petroleum refineries, aluminium, iron, steel and ceramics industries. All these industries use imported refractory bricks for the construction, lining, and thermal insulation of the various furnaces, kilns (rotary, tunnel, Hoffman, continuous, etc.), and kettles employed in the manufacturing processes. Different types of refractory bricks are imported: fire-clay, basic, high-aluminia, silica and insulating bricks.

Table 2 shows the quantities of refractory bricks imported by Jordan during the years 1986 to 1991 and their value in Jordanian dinars. The table shows an increase in local demand during the period covered.

Moreover, trade statistics indicate that the whole quantity is imported from Europe and East Asia (Italy, France, the United Kingdom, Germany, India, China and Japan). This indicates that the local refractory brick industry, if well established would be supported by the regional market as well as the local one.

Some of the raw materials needed for manufacturing refractory bricks are available in Jordan. This includes fire-clay, kaolin, quartz, sandstone, dolomite and olivine. Occurrences of these materials were mentioned earlier in this paper: note as well that olivine is available as an accessory mineral in many of the basalts in Jordan. Investigations revealed that the average forsterite ($MgFiO_4$) proportion in Jordanian olivine is suitable for refractory production (greater than 90%). Quantities have not been investigated yet. Such types of available raw materials indicate the production of certain types of refractory bricks, mostly fire-clay, basic and silica bricks.

A local refractory brick industry in Jordan would support the already existing large industries as well as those of new materials. The positive economic implications are obvious.

(c) *Fine ceramics*

Conventional ceramics (ceramicware, refractories, cement, glass) are produced by the high-temperature calcination of silicate and other natural raw materials. Although these ceramics are resistant to high temperature and corrosion, they are brittle and hard to work compared to polymers and metals. In contrast, fine ceramics are inorganic materials with specialized functions. They are manufactured from fine synthetic powders by using precision techniques to control the microstructures of the finished products.

Fine ceramics are classified into oxides and non-oxides. The oxides, which are manufactured by chemically processing pure natural raw materials, comprise nearly 90% of the raw materials used for fine ceramics. The oxide group includes aluminia (AL_2O_3), zirconia (ZrO), magnesia (MgO) and composite oxides such as barium titanate ($BaTiO_3$). The non-oxides are new materials mainly produced by artificial synthesis of less available raw materials. This group includes many modern materials that do not have the brittle characteristics of conventional ceramics. Such new materials include silicone carbide (SiC), silicone nitride (Si_3N_4), and zirconium carbide (ZrC).

Fine ceramics have different functions—insulating, semi-conducting, magnetic, thermal resistance and insulation, and biological compatibility—and may be classified as electroceramics, engineering ceramics, or bioceramics.

Fine ceramics are not produced in Jordan owing to the sophisticated technology required, in addition to the unavailability of most of the raw materials needed, especially the chemically pure substances. Fine ceramics are not even imported to be incorporated in finished products; they may be imported as parts installed within machines, devices or any end product.

Table 2. JORDANIAN IMPORTS OF REFRACTORY BRICKS

Year	Quantity (kg)	Value (JD)
1986	284 726	61 417
1987	550 419	113 363
1988	None	None
1989	468 885	273 287
1990	1 465 235	734 324
1991	2 817 242	1 985 043

(d) *Cement*

Cement, the "glue" in the most widely used composite material (concrete) is a typical representative of "low-technology" ceramics; it costs about four cents per kilogram to manufacture. The primary advantages of cement are low cost of energy per unit volume (for example, the cost ratio of cement to steel to aluminium is 1 to 18 to 30), the availability of cheap raw materials (clays and limestones), the relative ease of processing and the consequent low cost.

Cement must be considered as one of the basic commodities on which development programmes rely, with an importance comparable to that of water, fertilizers and energy; consequently self-sufficiency in cement production is always given a high priority in development planning.

1. *Exports and imports*

Jordan's cement industry is a net foreign exchange earner. Jordan exports considerable amounts of cement to Yemen, Sudan, Saudi Arabia and Egypt (1986-1989), and recently to East Asia (1990 and 1991).

Jordan started exporting clinker* in 1990, mostly to East Asia, including Singapore, Thailand, Hong Kong. Sri Lanka and the Philippines.

Following the devaluation of Jordanian dinar in 1988, cement exports increased, while they decreased in 1991 by around 43% compared to 1990, owing to the Gulf war. The war resulted in a lack of fuel for production, reduction in market demand, increase in shipping and insurance costs, and the blockage of Aqaba port.

The amount of cement that Jordan imports from industrialized countries (mainly European) has remained negligible and is restricted to certain special cements.

2. *Technology*

The cement industry in Jordan started in 1951 with one factory, the Jordanian Factories Company (JCFC), which had capacity of 110,000 by 1990. It had developed into three factories with a total capacity of 1,820,000 tonnes. Development in the production rate is given in table 3. The other two factories are the South Cement Company (SCC)/Rashadiya Plant, which merged with JCFC in 1985, and the Arab Company for White Cement (ACWCI)/Khaldiye

Table 3. CEMENT AND CLINKER PRODUCTION IN JORDAN
(Tons)

	Fuheis Plant		Rashadiya Plant		Khaldiye Plant	
Year	Clinker	Cement	Clinker	Cement	Clinker	Cement
1986	1 045 540	1 323 554	478 191	471 125	56 000	..
1987	1 029 080	1 276 732	1 077 771	1 096 346	..	36 797
1988	842 006	1 082 730	650 938	696 738	44 318	..
1989	770 075	1 005 035	825 820	924 978	..	67 000
1990	1 171 810	1 191 470	1 521 474	546 424	78 000	81 000
1991	1 351 360	1 272 270	1 400 133	402 591	..	..

Note: Two dots (..) indicate that data are not available or are not separately reported.

Plant, which is a joint venture between the Syrian Arab Republic and Jordan. The main characteristics of these plants are given in table 4, including their locations, kilns used, cement types produced and capacities.

Jordan produces several types of Portland cement: ordinary, pozzolana, sulphate-resistant and white.

The most recent developments in the technology of cement manufacturing are in favour of the dry process, which reduces fuel consumption to as low as 700 K cal/kg of clinker compared to 1,300 K cal/kg consumed by the wet process. Local cement plants have adopted this global trend, since fuel consumption accounts for about 45% of the cost of production.

To reduce fuel consumption further, Fuheis Plant (JCFC) has been using natural pozzolana[2] since the early 1980s to substitute a certain amount of clinker (around 20%). The production of (OPC) has led to a 25% reduction in the fuel oil consumer for clinkering, and consequently to a 10% reduction in total production cost (after considering the cost of the additional grinding required). Blending the pozzolana with clinker to produce PPC is one way to increase the output of cement from a given clinker production. Another way is to intergrind the clinker with an inert filler, usually limestone, to produce masonry cement. This latter method is under consideration by JCFC, especially since limestone is widely available in Jordan; preliminary studies have been conducted. It is noteworthy that the adoption of these new technologies by JCFC was based on successive research and development programmes performed jointly by JCFC and BRC/RSS.

In parallel with international awareness regarding the environment, the RSS on behalf of JCFC is conducting a study to monitor air pollution from the Fuheis Plant area. When the study is completed, the plant will adopt any necessary steps to protect the environment.

[2] The term pozzolana is employed to designate a siliceous or siliceous and aluminous material, which in finely divided form will react with slaked lime to form a hydraulic cement. Pozzolanas are classified into natural (tuff, volcanic ash, etc.), and artificial (fly ash, blast furnace slag, etc.).

Table 4. CHARACTERISTICS OF EXISTING CEMENT PLANS IN JORDAN

Company and Plant	Start of Production	Product	Capacity (tons/year) and number of kilns
Jordan Cement Factories Co. Fuheis Plant (south-west of Amman)	1954	Portland pozzolana cement	2,000,000 (6 kilns)
South Cement Co. (merged with JCFC in 1985) Rashadiya Plant (200 kilometres south of Amman, near Ma'an)	April 1984 (1st line) Oct. 1984 (2nd line)	- Ordinary Portland cement - Sulphate-resistant cement	2,000,000 (2 kilns)
Arab Co. for White Cement (Khaldiye Plant) Wadi Dhlail near Zarqa	Sept. 1985	White cement	10,000 (1 kiln)

3. *Raw materials*

The cement industry in Jordan has been always identified as one of the most feasible options for comprehensive development owing to the availability of raw materials. Large deposits of limestone, clay and gypsum, which are the basic raw materials for cement manufacturing, are available in Jordan.

(e) *Concrete products*

The industry of concrete products in Jordan is a diversified one, including cement and terrazzo tiles, bricks and blocks, drainage and sewer pipes, and kerbstones.

The industry of concrete bricks (for walls) and blocks (for roofing) is well developed and widespread around 1,200 brick-making plants are distributed all over Jordan, covering rural and urban areas. Floor tiles (cement and terrazzo) factories are also widely distributed, comprising nearly 300 plants. Terrazzo tiles are the most common floor tiles used in Jordan. There are around 10 factories producing drainage and sewer pipes reinforced and unreinforced, with diameters ranging from 150 to 1,200 millimetres. Concrete curbstones for sidewalks are produced and widely used in Jordan much more so than natural stone curbstones.

Concrete has already been used in Jordan to replace timber railway sleepers, since timber is an imported raw material. Prestressed concrete railway sleepers are produced locally for the use of the Aqaba Railway Corporation.

Concrete as a material contributes not only the development of the transportation sector, but also to the energy sector. Transmission prestressed concrete electric poles have been produced in Jordan since 1980 by a specialized plant that provides the Jordan Electricity Authority with the poles required to implement its plans for electrification of rural areas and the Jordan Valley area.

Lightweight concrete products are also produced in Jordan mostly by employing lightweight aggregates. Lightweight concrete-perlite units are manufactured locally using expanded perlite as a lightweight aggregate. The production process of expanded perlite particles from perlite rocks is performed at the factory. Such units are highly suitable for the thermal insulation of buildings. The factory produces bricks for walls as blocks for roofings.

1. *Concrete*

Construction in Jordan requires large amounts of concrete the traditional materials used for structural members.

Concrete cast in situ may be plain, reinforced or prestressed depending on the member being constructed.

Concrete materials may be measured and mixed by shovels—an inaccurate method, of course—or mixed in a batch mixer at the job site.

Ready-mixed concrete is further step along the road towards better technology. This type of concrete is prepared by a central plant to confirm to specifications for a given mix or to meet a specified strength.

Jordan has four ready-mixed concrete plants. The oldest one was established in 1974 and was responsible for introducing this new technology of concreting to Jordan. Ready-mixed concrete is included in the quality-control programme of BRC/RSS and DSM/MIT.

The concept of building with structural members which have been cast and cured in a factory rather than in situ has gained general acceptance in recent years. These prefabricated, reinforced or prestressed units go under the general heading of "precast concrete". Casting and curing conditions, as well as concrete design, can be more rigidly controlled, resulting in high quality concrete.

In Jordan, there is one precast concrete plant operating at the present writing; two plants have stopped production for economic reasons. The operational plant produces custom precast concrete units ordered for specific projects.

Chemical admixtures are being increasingly used in Jordan to meet the varying demands of different job sites. The use of superplasticizer will give concrete increased strength or an increase in workability.

Admixtures, in addition to other construction chemicals such as curing compounds, repair materials, sealants, etc., are available in Jordan, and their use is continuously increasing. They are mainly used in urban areas and in construction projects that need high-technology concrete.

These materials are mostly imported (by around 20 general trading companies); however, three local plants produce admixtures under license (using imported main chemicals and technology). Moreover, local attempts are being made to produce patching repair compounds with cementitious base.

Facilities for quality-control testing of admixtures and some other building chemicals are available, but these products are not yet enroled in the RSS quality control programme conducted at present. A specialized laboratory for testing the whole range of this advanced category of materials will be established at BRC/RSS in the near future through international technology cooperation.

Mortars used in Jordan for both plastering and masonry are cementitious; the traditional mix consists of cement, sand and fine crushed limestone, and in some cases lime is also added.

At present, the production of ready-mixed mortar is under consideration by JCFC, as it consists mainly of cement. The research and development needed for this new products will be performed most likely by BRC/RSS. Ready-mixed mortar is factory prepared and requires only the addition of water at the job site. Ready-mixed mortars usually provide a more uniform quality regarding strength, water retention and colour. Moreover, they are more practical, economical and environmentally safe.

In addition to admixtures, many other possibilities exist for modifying the properties of concrete: for example, various polymers can be incorporated in the fresh concrete (either by adding aqueous emulsion polymer during mixing, or by impregnating polymer into hardened concrete); also, concrete can be reinforced using fibres of steel, glass and carbon and natural fibres. The use of fibres allows the fabrication, by spraying, of thin sheets and forms which hold their shape during setting. glass-fibre-reinforced concretes have much higher flexural strengths than conventional concrete. This composite material industry can start up in Jordan once the local glass factory JGIC begins producing glass fibres as planned. Cement reinforced with natural fibres is usually more feasible for developing countries, but since organic materials are not available in Jordan, introducing such composites will be difficult. The wide range of materials that can be used in modern concrete technology is shown in table 5. New materials are making inroads in the building and construction sector. Although constrained by building codes and the slow transfer of technology, materials innovations offer a number of benefits, the principal one being the reduction of the lifecycle cost of a structure.

2. *Future perspective*

Cement, concrete and mortar will increase in importance as civil engineering materials because they will require less energy for production and use than other materials, and because they will be technologically better than today's products.

(a) *Demand*

Because of the large variety of materials included in concrete technology (shown in table 5) and the many possibilities during manufacture for changing the quality of the final product—concrete is one of the most flexible, versatile and adaptable materials available. It is as well suited for many low-technology uses as it is for sophisticated high-technology

Table 5. MATERIALS USED IN MODERN CONCRETE TECHNOLOGY

Binder systems	Aggregates	Reinforcing systems	Additives
Portland cements	- Natural sands and gravels - Crushed aggregates	- Ordinary steel bars - Wire mesh, glass, steel and polymer fibres	- Admixtures; retarders, accelerators, stabilizers, air-entraining agents, water-reducing agents
Blended cements	- Natural light-weight aggregates		
Special cements (with or without admixtures)	- Processed light-weight aggregates - Natural heavy aggregates	- Special-purpose steel bars and steel cables - Pre-stressing systems	- Fly ash, silica - Polymer dispersions, epoxy resins, emulsions
Cementitious materials, mostly reacting with water	- Inorganic and organic wastes - Special inorganic, organic products	- Glass-fibre tendon systems	

projects. Nearly all operations can be executed by hand, and yet the whole sequence can be mechanized and automated if desirable.

Experience shows that per capita cement consumption increases as gross national product (GNP) rises. Thus, in North America and Europe, annual consumption is 300-4,000 kilograms per capita, in South America, 100 kilograms, and in Africa and Asia, 50 kilograms. The figures for concrete are about an order of magnitude larger. Based on these figures, the economic future of cement and concrete is clearly assured, since most developing countries (including Jordan) are increasing their populations, GNPs, standards of living and degrees of urbanization.

(b) *Technology*

The technology of cement and concrete will develop along the lines outlined earlier in this section, namely, cement, aggregates, chemical admixtures, quality control and reinforcing types and systems. Cements having special properties, such as very early strength, will continue to be developed. Some of the new cements will require significantly less energy to produce than today's cements by employing waste products of cementitious properties. Significant developments will occur in the use of supplementary aggregates from waste materials.

Innovations in the use of chemical admixtures will continue to increase. The use of superplasticizers will give concrete increased strength or workability. Resin admixtures will control the modulus of elasticity and increase the resistance of the cement matrix to chemical attack.

In addition to materials that modify the properties of new concrete, maintenance and repair works require another category of materials (patching, caulking and grouting materials). There has been an increasing demand for repair materials in Jordan to maintain old concrete works. The production of these materials should be an important local target since demand should continue to increase, similar to the situation in developed countries.

Quality control will become more important, and new test methods will be related to civil engineering criteria for such characteristics as strength, durability and surface appearance. Concrete of the future will be composed of selected materials of greater uniformity of properties or higher quality, or both, in proportions dictated by the desired performance under specific conditions.

(c) *Applications*

Existing applications of concrete will continue but with changes in practice; for example, a new type of concrete may well replace the traditional concrete. The new concrete will be made using aggregates composed of earth materials as they exist at the site. The use of concrete pavements for highways will increase as shrinkage-compensating concretes and admixtures are developed to reduce cracks and joints.

In civil engineering, concrete is already an acknowledged competitor with other constructional materials. For example, concrete competes with steel for bridges and drilling platforms and with bitumen for road surfacing. Applications in other areas will continue to increase, for example, conventional reinforced concrete used for floating vessels, large concrete barges, floating docks and platforms for chemical plants.

H. MINERALS

Government expenditure for minerals has concentrated on mining, cement and agricultural-related large industries such as fertilizers and potash, the target being to fulfil the needs of the agricultural sector (since Jordan is basically an agricultural country) and of the construction industry. The driving force is the availability of the raw materials.

1. *The potash industry*

The potash industry utilizes two of Jordan's most abundant natural resources: solar energy and the mineral-rich brine of the Dead sea, which is estimated to have 43 billion tonnes of mineral resources. The industry's designed maximum capacity is 1.8 million tonnes of KCI per annum. Actual KCI production for the years 1987, 1988, 1989, 1990 and 1991 was, respectively, 1.20 million, 1.30 million, 1.32 million, 1.40 million and 1.36 million tonnes. About 90% of the produced potash is used in the production of fertilizers. it is also used in oil and gas drilling and in manufacturing caustic potash and sulphate of potash. The processing of KCI involves the following: increasing the concentration of salts, precipitation of carnality and processing it to obtain Falah sylvite native KCI sylvanite $AgAuTe_2$ which is then leached to dissolve KCI. The KCI-rich solution is then separated, and KCI crystallization occurs, followed by dewatering and drying to obtain potash that is made into granulars.

The potash raw material carnality is a corrosive agent. The involvement of temperatures up to 106°C increases the corrosiveness of the process, which requires the use of materials with high resistance to such conditions.

When constructed, the piping system, parts, etc., of the potash refinery were manufactured of special alloys such as Monel alloy and duplex stainless steels, mainly ferralium 255 by weight 25% chromium, 5% nickel and 1.4% molybdenum. These parts performed well for two to three years and then problems of leakage started. The situation deteriorated especially after making welding repairs on duplex stainless steel parts which performed excellently in their wrought condition. Modifications to the lines were made, using ceramic-lined mild steel pipes. Problems became noticeable after a while.

The factory was recently advised to use expensive Inconel alloys instead, and it is hoped that good results will be obtained, from making this change. Conditions at the site of the potash industry—salts concentrations, corrosivity, temperature and humidity—require rigorous applied research that should be carried out jointly by the Arab Potash Company R&D bodies in Jordan (such as the RSS) and abroad, and the suppliers of the equipment used in production. This would make possible the establishment of a data bank on the area, as well as an experimental pilot plant, and would lead to the development of suitable materials, designs and maintenance methods.

The Dead Sea has huge resources of potential materials to be produced, and studies on the production of potassium sulphate, sodium carbonate, bromine and its derivatives, magnesium oxide and compound fertilizers are being carried out. these will help develop the potash industry in Jordan and will provide virtually endless resource of income. The development of this industry will provide job opportunities in the Kerak and Ghor Al-Safi area through the establishment of a large chemical complex.

Again, the importance of establishing the previously mentioned research network is emphasized, as well as the importance of providing spare parts and alternatives made of advanced materials developed on the basis of research that suits Jordan's (and severe) environmental conditions.

2. *The phosphate industry*

Jordan has enormous resources of phosphate ores with high-quality P_2O_5 content; these are extracted at four operating mines at various locations and are processed at a phosphatic fertilizers complex in Aqaba.

Jordan Phosphate Mines Company (JPMC) was established in 1953 to exploit phosphate rock reserves in the Rusaifa area. The company expanded to include El-Hassa mine in 1962, El-Abyad mine in 1979 and Eshidiya mine in 1988. The fertilizers complex at Aqaba was established in 1982. The total proved reserves of phosphate in the sites are shown in table 6.

Table 6. PHOSPHATE RESERVES IN JORDAN

Site	Rusaifa	El-Abyad	Eshidiya	El-Hassa	**Total**
Reserves (Millions of tonnes)	65	66	790	110	1 031

Jordanian phosphorite consists of cryptocrystalline apatite, in which flouride and/or chloride are replaced in varying amounts by OH or CO_3.

Phosphate rock is a vital natural resource and is the main source of phosphorus, a major plant nutrient. About 90% of the phosphate rock mined is used in agriculture, primarily in the production of soluble fertilizers, while the other 10% is used in medical and chemical industries to make such products as detergents and cosmetics.

Phosphate rocks mined in Jordan are of superior quality and softness and have high porosity and reactivity, high purity and low chlorine content, making them grindable with low power consumption, of high yield, suitable for producing pure phosphoric acid and of low corrosivity.

Jordan is the world's third largest phosphate rock exporter after Morocco and the United States. Table 7 shows the annual production of phosphatic products in Jordan. Jordanian production of phosphate rock, diammonium phosphate, and aluminium fluoride are exported to more than 21 countries worldwide. Phosphoric acid is exported mainly to Indonesia and India.

JPMC's exports of phosphate rock, phosphatic fertilizer and other chemical derivatives since 1985 are shown in table 8.

The production of phosphate and its derivatives involves mineralogy, ore dressing, ore bonification and mineral processing. In these processes heavy machinery such as drilling rigs, drag-lines, loaders and crushers are used. Many metallic parts are consumed when operating these machines. High rates of wear occur often for those parts in direct contact with the phosphate rocks. A good example is the tooth used in drag-lines, which is made of steel alloy and which has a lifetime of only 24 hours owing to its low hardness and resistance to wear.

Table 7. JPMC PRODUCTION OF PHOSPHATIC PRODUCTS
(*Thousands of tonnes*)

Year	Phosphate rock	Phosphoric acid	Diammonium phosphate	Aluminium fluoride
1985	5 920	260	495	6
1986	6 246	282	551	10
1987	6 801	283	605	11
1988	5 561	303	615	15
1989	6 910	303	602	16
1990	6 082	297	596	15

Table 8. JMPC EXPORTS OF PHOSPHATIC PRODUCTS
(*Thousands of tonnes*)

Year	Phosphate rock	Diammonium phosphate	Phosphoric acid	Aluminium fluoride
1985	4 610	509	32	6
1986	5 198	559	22	13
1987	5 544	566	10	11
1988	5 811	629	14	16
1989	6 411	579	22	16
1990	4 874	613	18	16

The development of a new alloy with mechanical properties better suited to such application would result in greater efficiency of the drag-line and would eventually reduce the overall production cost of phosphate rock.

Advanced materials technology plays a major role in the repair works of worn parts. Renewing used metallic parts such as gears, teeth, pulleys, hammers and chains using welding technology is often applied. This requires advanced processes and new alloys for filler materials suitable for hard facings and other applications.

In the fertilizer complex at Aqaba, phosphatic fertilizer, phosphoric acid, diammonium phosphate, aluminium fluoride and sulphuric acid are produced. The production lines are mechanized, and the processes are either automatically or semi-automatically controlled.

The processing of the above-mentioned products involves chemical treatments and requires power and materials. The use of metallic components of suitable mechanical, metallurgical and corrosive properties is of vital importance to ensure continuous and safe production. In addition, implementing methods of corrosion protection and control, such as cathodic and anodic protection of huge tanks, is essential to extend the lifetime of such units and hence reduce maintenance cost.

Phosphate in Jordan is a material of great potential that is used in various industries and which affects industrial development in Jordan both as a raw material and as processed one.

I. Conclusions

1. Jordan has a population growth rate above the world average, a situation that creates a high demand for materials.

2. Jordan is generally a consumer of more traditional and less sophisticated materials, although knowledge about new materials being used in the industrialized countries is available.

3. Jordan is still dealing with basic materials, while industrialized countries are developing materials that have a high-technology content.

4. A large group of the basic materials developed and produced in Jordan are employed in the construction sector. This is in full agreement with the fact that housing is a basic need for a developing country with a rapidly growing population. Services associated with housing (water supply, electricity, sewage treatment, etc.) also need to be expanded. In Jordan construction constitutes approximately one third of all fixed capital investments.

5. Most of the basic materials developed in Jordan and used for construction are inorganic such as stone, brick, cement, lime, etc. This is largely due to the fact that the demand for building materials for traditional or conventional construction patterns, which are widespread in Jordan, is largely conditioned by the local availability of such materials. The type of building materials available varies from one region of the world to another, depending on climatic conditions. Thus Jordan, since it is a hot, dry region lacking organic materials such as timber and bamboo which grow well in warm, humid regions, uses inorganic materials for construction.

6. The metallic industries in Jordan are primarily transforming industries that depend largely on imported raw and intermediate materials. The state of the art in these industries varies widely: some industries are well equipped and advanced such as aluminium extrusion and canning, and others such as small foundries still use primitive methods of production and lack expertise and quality control.

7. The use of advanced materials in Jordan's phosphate fertilizer complex and potash industry is obvious. The proper selection and development of materials for the devices used in the production lines of these factories under their specific working conditions is essential to maintaining a stable rate of production and a reasonable lifetime of components.

In Jordan, as in most developing countries, the rate of materials development has been slow compared to that of the developed countries, where resources and demand exist for research and development. however, the structural elements of a framework on which future developments in materials science and technology could be built already exist in Jordan. Such elements include:

(a) Education systems that provide qualified human resources, universities with undergraduate and graduate programmes that have strong ties to external centres of excellence. There are four government universities in Jordan, in addition to five private universities;

(b) Scientific research institutions to promote research and development, and utilize science and technology. Scientific and technological services grew rapidly in the last decade in Jordan. The Royal Scientific Society, established in 1970, has made a significant contribution through its specialized industrial laboratories. It has been successful with testing and quality control, but less successful in the utilization of local materials. Development of new materials has been minimal. This is largely due to the fact that all these activities have been conducted by a number of research centres and not through a "materials science and technology centre" as is the case with developed countries. In fact the Five Year Plan for the Economic and Social Development of Jordan (1986-1990) recommended the establishment of a materials science centre of excellence (as one of the organizational measures included in the science and technology sector). Unfortunately, the centre has not yet been established;

(c) Readily available access to scientific and technical information. Adequate facilities for communication with data banks worldwide is another goal that has been partly implemented in Jordan through the establishment of the National Data Bank Centre;

(d) Intensified attention given to national standards and meteorology in Jordan by the Directorate of Standards and Measures at the Ministry of Industry and Trade. A good number of standard specifications have been enacted covering all types of products including polymers, metals and ceramics. Moreover, general building specifications and national building codes have been prepared by BRC/RSS on behalf of the Ministry of Public Works;

(e) Provision of research and development units at the factories of large industries in Jordan such as phosphate, potash, and cement. These units serve also as quality-control units;

(f) Provision of local laboratories belonging to the Government to exploit local resources for local needs. The Natural Resources Authority/Ministry of Energy and Natural Resources established 1966 plays an effective role in the utilization of natural raw materials, which are very closely connected to new materials development.

J. RECOMMENDATIONS

The primary goal of building up the national capacity in materials technology is to enhance the ability to make independent, effective decisions about the development of materials technology resources. Decisions must be made on many levels simultaneously including identifying and selecting markets, establishing and maintaining institutions for testing and quality control, and managing the scientific community and the different, yet related, technology enterprises. To implement such a national goal this paper recommends the following:

(a) Establishment of a materials science and technology centre, having the following objectives: to evolve a national policy based on technological forecasting and assessment; to develop a coherent long-term strategy for materials; and to develop the capability of participating in the evolution of international materials policy. Such a centre should determine the optimum directions of research, development and production of materials. This would provide maximum benefits in fulfilling basic human needs by using quantitative techniques of technology assessment from a local perspective;

(b) Strengthening the links between materials science and technology institutions, universities, industry and Government to influence national materials policy through several mechanisms such as consultancy, sponsored research work, exchange of personnel, conducting seminars and short courses for personnel in industry and Government, and formation of national materials advisory boards. Such linkages would result in highly-competitive industrial products;

(c) Advancement of materials technology should be considered by the Government through public procurement, the setting of standards, the granting of patents, and the funding of research and development. The Government is the largest single purchaser of goods and services. Therefore, by using public procurement specifications, the quality of goods can be raised, and also the technology involved in producing them;

(d) Increasing international and regional cooperation in such matters as development of research programmes, interchange of materials scientists and engineers, expansion of centralized facilities, setting materials standards, exchanging technology assessment and forecasting and development of mechanisms for the transfer of information on materials science and technology;

(e) Acquiring new technologies through technology transfer. The most practical strategy for materials technology development could be to combine two options: developing technologies through allocating resources for research, and direct purchase of technology from developed countries;

(f) Revalorization of science and technology. This would help the country solve the problem of the increasing difficulty of retaining the few experts available in any given field. The present brain drain is largely due to lack of valorization of the experts' activities in an undeveloped society;

(g) Increasing cooperation between Jordan and other developing countries in programmes of mutual interest. Success in materials development could be enhanced by minimizing risk.

REFERENCES

1. Centre for Science and Technology for Development, *Bulletin of the Advanced Technology Alert System*, "Material technology and development", United Nations publication, Sales No. E.87.11.A.2.

2. Economic and Social Commission for Western Asia, "Status of the building materials and construction industries in the ESCWA region" (E/ESCWA/HS/85/6).

3. Economic and Social Commission for Western Asia, "Issues of inter- and intraregional trade and marketing of manufactured products," United Nations Industrial Development Series, No. 11 (E/ESCWA/ID/89/9), 1989.

4. United Nations Industrial Development Organization, "Appropriate industrial technology for construction and building materials," Monographs on Appropriate Industrial Technology, No. 12, 1980.

5. M.M. Abu-Ajamieh, F.K. Bender, R.N. Eicher, *Natural Resources in Jordan: Inventory-Evualuation-Development Programme*, Ministry of Energy and Mineral Resources/Natural Resources Authority, Amman, 1988.

6. Oliver and David, *Metals, Ceramics and Polymers: an Introduction to the Structure and Properties of Engineering Materials*, (Cambridge University Press, London, 1974).

7. United Nations Industrial Development Organization, "Building materials industry", UNIDO Monographs on Industrial Development, No. 3, United Nations publication, Sales No. E.69.11.B.39, vol. 3, 1969.

8. United Nations Industrial Development Organization, "Management of industrial research and service institutes in the building materials and construction sector in developing countries", Sectoral Working Paper Series, No. 66, PPD. 70, December 1987.

9. F. Sarraf, I. Katkhuda, "Clay and clay bricks in Jordan, previous studies and existing situation", Royal Scientific Society, Amman, December 1981.

10. I. Ibraheem, S. Mehyar, S. Abed El-Jawad, I. Syriany, "The plastic industry in Jordan", Royal Scientific Society, Amman, 1979.

11. A. Tawalbeh, "The needs of Jordanian Industry in the field of mould design and manufacture". Royal Scientific Society, Amman, 1990.

12. Jordan, Department of Statistics, *Statistical Yearbook* (No. 41), 1990.

13. Jordan, Department of Statistics, "External trade statistics", vol. I and II, 1990.

14. Jordan, Amman Chamber of Industry, *The comprehensive manual of Jordan industries, 1990/1991.*

15. Jordan, Ministry of Planning, "Five-year plan for economic and social development, 1986-1990".

16. Saechling, "Plastics Handbook", Carl Hanser Verlag Press, 1987,

17. Economic and Social Commission for Western Asia, "Industrial development in the Hashemite Kingdom of Jordan" (E/ESCWA/ID/89/6), 1989.

18. Jordan, Ministry of Energy and Natural Resources, Natural Resources Authority, "Mineral occurrences in Jordan", Guide Book, 1988.

19. The Jordan Cement Factories Company (JCFC), annual reports for the years 1985 to 1991.

20. Jordan Ceramics Industries Company (JCIC), annual reports for the years 1985 to 1991.

21. Jordan Glass Industries Company (JGIC), annual reports for the years 1987 to 1991.

22. The Arab Company for White Cement (ACWCI), annual reports for the years 1984-1990.

23. Arab Potash Company (APC), Annual Report, 1991.

24. Jordan Phosphate Mines Company (JPMC), Annual Report, 1991.

25. National Iron and Steel company (JPMC), Annual Report, 1991.

26. Jordan Iron and Steel Company (JISC), Annual Report, 1991.

27. Arab Aluminium Manufacturing Company (ARAL)/Jordan, Annual Report, 1991.

Discussion of Part Three, Paper Two

Mr. Ghazi Derwish

Q. Does the information presented under advanced policy represent any order of priorities for materials considered in Jordan?

No, I just listed plastics because I listed polymers first, followed by the metals and then the ceramics.

Mr. Ghazi Derwish

Q. In one of the transparencies, you had a list of materials to be considered for manufacturing in Jordan. Are they in any order of priority?

No, they are not.

Mr. Abd El-Hamid Attia

I have a comment. From the papers presented yesterday and today and after listening to the three presentations from Egypt, the Syrian Arab Republic and Jordan, I would like to comment, first that many industries have been represented in the papers. But as Mr. Derwish pointed out in his question, no priority has been established yet. In my opinion, it is important to call for a meeting, as mentioned by UNIDO representatives, similar to the UNIDO meeting in Bangalore, which was held for advanced materials policies and strategies last year, and the meeting in Latin America and Africa, for the ESCWA member countries to examine strategies especially for the industries and problems at the individual country level. The huge cost of entering these areas may give us an idea about the priorities which we have to set. This should be done at a regional level as recommended by the UNIDO meetings for the Latin America and the African countries.

I think the materials I listed here are preliminary. They need to be studied and investigated. For example, the refractories mentioned in the paper, if they are to be produced in Jordan, they should be useable in the region because although we calculated the quantities imported by Jordan for all the industries it is still not feasible to establish such an industry in Jordan, unless other countries in the region will benefit from the production. We have the raw materials; we need some high technology. The potential is there and it needs more studies, mostly feasibility studies.

Paper Three

NEW MATERIALS: IMPLICATIONS AND OPPORTUNITIES THE CASE OF THE SYRIAN ARAB REPUBLIC

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I. THE STATUS OF NEW MATERIALS IN THE SYRIAN ARAB REPUBLIC

The manufacture and utilization of new materials in the Syrian Arab Republic has been exceedingly limited. In the 1970s several operators set up artisan facilities for producing fibreglass-resin composite structures, mainly water tanks for domestic and agricultural purposes. Economic stagnation during the 1980s created an atmosphere of extreme caution on the part of investors with the result that relatively few new industrial facilities were set up and limited developments, if any, took place in existing production facilities.

However, owing to recent significant changes in economic policy, a resurgence of industrial activity has been taking place in the country. Two recent projects which have already been awarded licences by the Syrian Ministry of Industry are noteworthy. The first is intended to produce, under licence from an Italian firm, small-medium size speedboat hulls using fibreglass-resin composites. The second involves building refrigerator truck bodies using the same basic material. Work on both projects is to commence shortly. Interestingly, both are located south of Damascus, rather than close to the Syrian coast, which would seem a more logical choice for the first project at least. The main reason for this is to capitalize on the chosen location's strategic position in relation to exports to Jordan, Lebanon and the Gulf region.

Several plans were made, particularly in the late 1980s, to set up within the framework of the Centre for Technology Development (CTD) at the Higher Institute of Applied Science and Technology (HIAST) specialized facilities for manufacturing microelectronics devices including integrated circuit chips. Manufacturing such products would certainly have required the utilization of some advanced materials. The requirements of such activities in the realm of new and advanced materials are numerous and varied. Not only ceramic and silicon materials will be required, but also organic polymers and a host of specialty chemicals will be necessary. An incremental approach has been adopted in this project, and once the core facility is established other related facilities will also be set up.

Plans are still being negotiated for erecting a silicon foundry through a cooperative programme involving, apart from HIAST, the Supreme Council of Scientific Research in Algeria. When established this facility should satisfy the demand for silicon chips both for electronic and solar-energy applications. On the downstream side, negotiations with a number of foreign firms and organizations, such as the Council for Scientific and Industrial Research of India, are under way. The aim is to set up a production facility for packaging photovoltaic systems for small power applications. It is quite likely that at least a pilot facility will be set up shortly.

More recently, at the Arab School's Winter session on Composites and Advanced Materials; Technology and Development (see annex, page 441), it was proposed that an Arab centre for materials research (ACMR) be established. It is suggested that ACMR should be hosted by HIAST, forming another important component in its Centre for Technology Development. It has been provisionally agreed with the United Nations Industrial Development Organization (UNIDO) that a feasibility study be conducted to clarify the mission of ACMR. This study should determine ACMR's institutional and human requirements and should include a preliminary market survey of technical capabilities and requirements in the Arab region. It is hoped that sufficient funding for this study will shortly be provided. A noteworthy element in the general plan envisaged for ACMR is its strong inclination towards local industrial activities on the one hand and its strong interaction with other regional and international organizations with the aim of coordinating research, development and standardization activities.

A. Specific areas of future application of new materials in the Syrian Arab Republic

Data concerning the growth of several important areas of the Syrian economy are shown in figure I. Of the areas represented in this figure, the construction and manufacturing industries are the most likely to be involved in the utilization, manufacture and dissemination of new materials and products incorporating them. The following paragraphs briefly analyze the prospects of new materials in some of the industrial activities mentioned above.

B. New materials in building and construction

Figure II summarizes data about the growth of spending on construction in the Syrian Arab Republic during the years 1981-1990, in billions of Syrian pounds. The building and construction sector has always constituted an important part of the Syrian economy. It is reported to have contributed around 11% to the gross domestic product in 1985 and 1986.[1] Although its contribution is reported to have fallen (4% in 1990), the building and construction sector still has considerable room to accommodate innovations in the materials utilized by it. It is also important to stress that the "new" materials which could be utilized by this sector are not necessarily new, or entirely new, materials. The literature abounds with reports of new combinations. These include modified or reinforced cement, gypsum, and plaster of Paris formulations. Introducing materials such as synthetic,[2] or natural-fibre reinforced mortar,[3,4] for example, should not (in theory at least) require large investments. Nevertheless, considerable efforts have to be made to examine the ageing characteristics of such materials and their compatibility with local conditions. This would obviously have to be done by specialized local R&D teams. It is almost certain that even apparently simple innovations made within local R&D facilities—if well coordinated—will often trigger significant changes within and outside the construction sector.

C. The glass industry in the Syrian Arab Republic

The first major glass factory in the Syrian Arab Republic dates to the early 1940s. Even after half a century, however, the range and quality of the glass industry's products leave a lot

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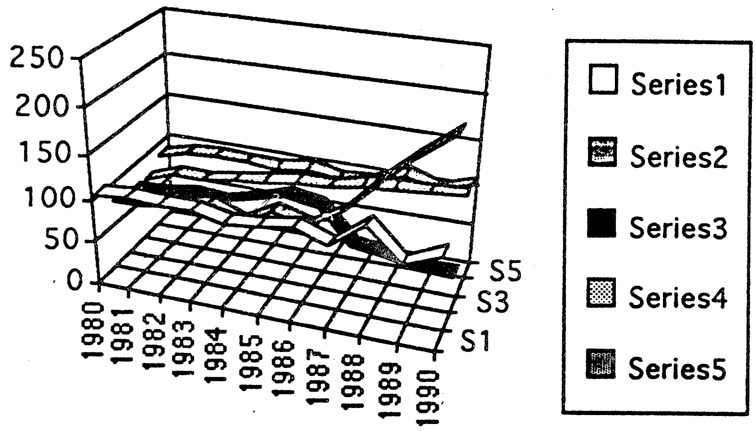
[1] Syrian Arab Republic, Office of the Prime Minister, Central Bureau of Statistics, *Statistical Abstract: 1991*.

[2] Y. Wang, "Tensile properties of synthetic fibre-reinforced mortar", *Cement and Concrete Composites 12* (1990), 29-40.

[3] Twenty-five plants have started up since 1968, 11 of them in the former Soviet Union, between 1985 and 1988. A further 14 plants are under construction in Hungary, Czechoslovakia, Germany, Iran, Turkey, the former Soviet Union, Japan, Argentina, England, Bulgaria and the People's Republic of China.

[4] A.A. Moslemi, "Inorganically bonded wood composites," *Chemtech*, August 1988, p. 505.

Figure I. GROSS DOMESTIC PRODUCT (GDP) GROWTH IN AGRICULTURE (SERIES 1), MINING AND THE MANUFACTURING INDUSTRIES (SERIES 2), BUILDING AND CONSTRUCTION (SERIES 3), AND THE TRANSPORT SECTOR (SERIES 4), TOGETHER WITH THE TOTAL OF ALL SECTORS OF THE SYRIAN ECONOMY (SERIES 5).



to be desired. Table 1 provides information about the output of the glass industry in the Syrian Arab Republic during the years 1984-1988.

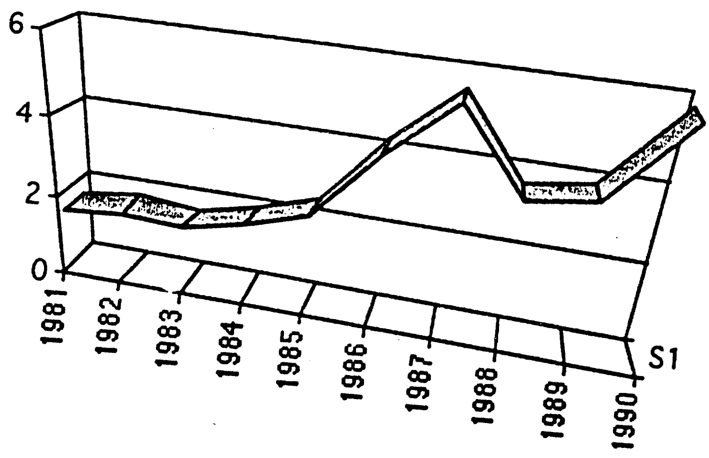
Despite the fact that ordinary glass and ceramic products manufactured in the country cannot be regarded as new materials, it must still be true that a certain rudimentary experience in these materials does exist in the Syrian Arab Republic.

HIAST has for about four years played host to an optical glass facility which was set up with the help of UNIDO. The facility is capable of processing imported optical glass castings through the various stages involved in the manufacture of lenses, prisms, mirrors, special screens and other components used in microscopes, telescopes and other educational, laboratory and medical equipment. The present facility has metal-coating capabilities, using vapour deposition techniques, as well as advanced testing and quality-control instrumentation. There are plans for extending the capabilities of this facility by importing a small foundry specializing in producing optical-quality glass. The initial projected output of the foundry is about 6 tonnes per annum. Once this is operational it is hoped that the country will possess an integrated capability in the field of high-quality optical glass. Given the somewhat limited domestic demands, it is only logical that export markets, at least in the Middle East, be explored.

Another project, which is being followed up within the framework of the Centre for Technology Development, concerns setting up a glass foundry having an estimated annual production capacity of about 10,000 tonnes. The glass produced in this foundry will be of quality that can be used in the manufacture of industrial and laboratory equipment which come into contact with all sorts of chemicals.

Figure II. GROWTH OF SPENDING ON CONSTRUCTION IN THE SYRIAN ARAB REPUBLIC DURING THE YEARS 1981-1990.

(Billions of Syrian pounds)



A recent study[5] that aimed at formulating a Syrian science and technology (S and T) strategy noted that the Syrian Arab Republic still buys millions of medicine bottles for its recently born and thriving pharmaceutical industry. Perhaps the above-mentioned facility for producing glass for chemical applications might be utilized or expanded to produce glass suited to pharmaceutical purposes.

In this connection, the following may be mentioned: A newly established private-sector pharmaceuticals company in the Syrian Arab Republic recently decided to produce glass to bottle its products, using sand imported from Belgium. This was contemplated while extremely pure sand is in fact quarried in the middle of the country. The reasons given for this apparently uneconomical decision are: lack of confidence in the analyses performed within the country on the sand samples submitted for trial as raw materials; uncertainty about the uniformity of the raw material quality; and the licensing company's insistence that the imported sand be used.[6]

This should serve to highlight the importance of providing reliable information about locally available raw materials and ancillary, analytical and other S and T services, in order to promote the production of new materials.

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[5] J. Mullin, "Towards a science and technology strategy for Syria"; a report prepared with the support of the United Nations Development Programme, December 1991.

[6] Personal communication obtained through J. Mullin, freelance consultant and former vice-president of IDRC, Canada.

Table 1. PRODUCTION FIGURES FOR GLASS IN THE SYRIAN ARAB REPUBLIC DURING THE PERIOD 1984-1988

(*Tons*)

Year	Sheet glass (SG)	Strengthened SG	Plastic reinforced SG	Patterned SG	Containers and bottles	Totals
1984	26 083	263	121	15 108	12 969	41 575
1985	20 872	203	26	14 918	5 914	36 019
1986	24 562	310	77	6 917	15 134	31 866
1987	20 947	257	47	14 614	4 248	35 865
1988	23 810	218	8	11 140	11 600	35 176

Source: Syrian Arab Republic, Central Bureau of Statistics, Office of the Prime Minister, *Statistical Abstracts*, 1990.

Note: The *Statistical Abstracts* issued in 1991 do not provide separate statistics for glass production. Instead, glass output is lumped with ceramic products. The date is given as follows (in thousands of tonnes):

Year	1986	1987	1988	1989	1990
Public sector	57	43	51	50	38
Private sector (glass only)	7.1	1.4	2.6	1.1	1.5

D. ELEMENTS OF A MATERIALS S AND T POLICY FOR THE SYRIAN ARAB REPUBLIC

There is basically no national policy relating to new materials in the Syrian Arab Republic, which indeed has yet to develop an integrated S and T policy in general.[7] However, waiting for this to happen may not be the best course of action to follow. It may be useful, albeit to a limited extent, to try to formulate sectoral and disciplinary policies which take into account the needs of the economic activities in the country, and yet which are flexible enough to permit their integration at later stages. Such needs may well have to be inferred from the various types of plans put forward by official bodies, and by intelligently charting and analyzing the course of international, regional and local developments.

Such an exercise falls outside the scope of this paper. However, a few points which may be of some help in arriving at policies such as those described above[8] will be briefly discussed below.

Table 2 includes the names of the ministries and institutions which should need a clear understanding of the significance of new materials development, including the threats and

[7] *Heeding the Call of the Wild*, I. Amato, vol. 253, 30 August 1991, p. 966.

[8] Reference should be made here to the summary of the studies conducted for the ALECSO project Strategy for Science and Technology Development for the Arab Countries; this was published in Arabic by the Centre for Arab Unity Studies in Beirut, 1989. Both English and French translations have recently been issued by ALECSO in Tunis. The question of S and T policy is discussed in general in this summary. Furthermore, issues related to new materials are accorded some consideration.

Table 2. MINISTRIES AND OTHER BODIES IN THE SYRIAN ARAB REPUBLIC WITH INTEREST IN NEW MATERIALS

Bodies[a] which utilize utilize new materials to a limited degree[b]	Bodies[a] which are likely to use new materials in future	Bodies[a] which should become involved in new materials policies
Communications	Agriculture	Office of the Prime Minister
Defence	Irrigation	Economy & Foreign Trade
Industry	Housing and public utilities	Environment
Transport	Oil and mineral resources	Health
Electricity	Public works and hydraulic resources	Higher Education
		State Planning Commission
		Building and Construction
		Supply and Internal Trade
		Social Affairs and Labour

[a] Mostly ministries or departments thereof.
[b] Almost entirely in the form of products incorporating new materials.

opportunities they pose.

One of the tasks to be conducted in the quest for workable S and T policies regarding new materials may well have to do with collecting, collating and disseminating useful information and analyses about them. Clearly, this could be done through films, television programmes, round-tables and publications of the ministries involved in the formulation of new materials policies.[9] Little can be achieved in formulating a science and technology policy for new materials without properly coordinating the views of experts and the needs of users. This coordinating function would be facilitated by a thorough analysis of such views and needs. On another level, it will be necessary to introduce students both at schools and at universities to new materials in a manner which reflects their future potential.

The role that could be played by indigenous and innovative R&D in the field of materials was mentioned above. Two important goals have to be considered in this respect. First, it is necessary to provide the infrastructure required for successful materials R&D. Second, it is essential to link R&D efforts to commercialization as much as possible.

[9] It should be noted here that enquiries at these ministries showed that very little, if anything, was being done under the heading of new materials technology from the standpoint of policy and regulation. Some of these institutions are, or will be, handling new materials, in the form of optic fibres for example, at the national post, telephone and telegraph (PTT) establishment. Engineers from this establishment are being trained in communications systems based on optic fibres. However, it is highly unlikely that integrated capabilities in the design of such systems will be gained from this exercise.

Another important policy issue which should be considered is the question of backward integration, in order to produce locally at least some of the new materials needed within the country and in the surrounding region. The usefulness of backward integration depends, of course, on the existence of a manufacturing base which stands to benefit from domestic production of new materials.

In conclusion, a useful approach to adopt in formulating a materials S and T policy might be to target, at least initially, areas in which "technological maturity" or near maturity has been achieved. This would have several advantages in terms of saving time and acquiring the necessary confidence to face more difficult challenges in the future. However, the act of identifying those areas of materials technology which have indeed reached a mature stage in their development is no small task. There is the further problem of deciding which of these mature or semi-mature technologies would be relatively more compatible with local economic, social and environmental conditions.

A good deal of effort, therefore, has to be directed towards rationalizing choices in the field of new materials. In the final analysis, the optimal choice will be one that: looks ahead at likely developments in technology and raw materials availability; answers, as profitably as possible, well-defined needs; takes into account the social and environmental implications of the products and processes involved; and paves the way for more ambitious work in the future. All this requires intensive endeavours in technology assessment and forecasting.

Annex

INFORMAL NOTE ON THE ESTABLISHMENT OF AN ARAB CENTRE FOR MATERIALS RESEARCH (ACMR)

1. *Justification*

It was widely recognized that materials science and technology are multidisciplinary in nature and transsectoral in impact. This should be taken into account by developing countries in making the decision to build up and/or strengthen their technological capabilities in the area of materials science and engineering.

Furthermore, it is expected that new materials will pervade world economies including those of the third world. It is therefore proposed that an Arab centre for materials research (ACMR) be established to meet the needs of developing countries in the Middle East. The regional character of this centre would concentrate limited financial and human resources and promote regional cooperation in the fields of materials science and engineering which have been the subject of extensive development efforts in the industrialized countries and which have in numerous cases reached maturity. The proposed centre would strongly interact with local industries and positively affect the development of human resources.

ACMR would have be multidisciplinary and would therefore concentrate on the transsectoral aspects of materials R&D work, including the characterization and testing activities with which the Arab countries are specifically concerned nowadays. It would focus on the needs of developing economies to produce new materials and/or enhance the added-value of their natural resources. For the same reason their imports should be drastically reduced. The R&D work carried out within ACMR would be taken into consideration with the environmental aspects and energy-saving problems of materials production and utilization.

2. *Objective*

The objective of establishing ACMR is to develop/strengthen the technological capabilities of developing countries in the Arab region in the area of research, development, production and utilization of new materials.

3. *Functions*

(a) To collect, assess and disseminate relevant information in the field of materials science and engineering, including information related to market needs and opportunities;

(b) To carry out joint R&D work in the area of design, manufacturing, testing and evaluation, and utilization of new materials;

(c) To render advisory services to other R&D groups/laboratories and to the industries dealing with materials issues;

(d) To make available the facilities and services of ACMR to research groups and industry;

(e) To organize and conduct seminars, workshops and training courses in the subject under consideration.

4. *Modalities of implementation*

ACMR can be implemented as a joint project involving UNIDO and a selected number of regional and national institutions. The establishment of ACMR should be carried out in a number of well-defined phases, the first of which would have to be a feasibility study, to be followed by a detailed planning study; later phases would be executive in nature.

The feasibility study (phase I of the project) should do the following:

(a) Determine the preliminary scope, structure, financing and human resource requirements as well as work programme of ACMR;

(b) Conducting a market survey and an analysis of technical capabilities in the region.

A draft proposal concerning the above tasks will be drawn up and submitted to the sponsoring and participating organizations for their comments, in the light of which a final proposal will be drawn up. (It is hoped that the draft proposal will be discussed at an expert meeting.)

It is suggested that the feasibility study be conducted by a team comprising an international expert in the field of composite materials and a senior scientist/technologist from the region with a background in strategic planning. These two experts should work closely with experts from UNIDO and other regional organizations such as ESCWA, the Regional Office for Science and Technology for the Arab States (ROSTAS) of UNESCO, etc.

It will be necessary for this team to organize a short tour of at least some of the countries in the region and to consult with local experts and end-users. Furthermore, it will be essential to visit active centres of materials research in at least one industrialized country with which cooperative activities might be conducted in future.

Discussion of Part Three, Paper Three

Mr. Ghazi Derwish:

Q. On the question of restrictions on technology transfer in advanced materials, I think this section is very short but very enlightening. In any materials science and technology policy, one has to be aware of the restrictions imposed on the transfer of information regarding advanced materials and new materials. The annex to the paper is very enlightening. In appendix I there is reference to the United States restrictions if I am correct.

Mr. O. Bizri:

This is a United States committee, but the restrictions have been taken up by the industrialized world.

Mr. Ghazi Derwish:

In any case, it makes very interesting reading because it suggests that one has to look seriously into some sort of materials policy, as the speaker has correctly pointed out. If the United States policy is followed by other advanced countries, then that will definitely block the way to any meaningful transfer of technology in this important field.

Mr. Abd El-Hamid Attia:

Q. I would like to know what are the capacities in the Syrian Arab Republic. I mean the R&D centres which will be involved in the implementation of strategies in the area of new and advanced materials? I think that, in your presentation, this point, which I am looking forward to knowing about for future cooperation in the region, is a little bit missing. So would you be so kind as to shed some light on this and on the available manpower?

Mr. R. Bassyouni:

Q. Just to comment on Mr. Derwish's remark concerning the regulations, I have received in the last month the new regulations of the United Kingdom and of Germany. They have serious restrictions. The United Nations should make recommendations against such practices.

Mr. Ali Dajani:

Q. I have three questions. First, on what grounds did you separate the science and technology policy and the materials policy? Science and technology has to do with materials, and materials are subject to science and technology for development and advancement, and I think separating the two will cause some confusion. They should be interrelated because they interact. This is one thing.

The second question is: are we thinking provincially or are we thinking regionally or internationally? We are on the international level, following the steps of the United States, Europe and the others. To what extent are we going to cooperate and implement policies regionally? Because to set up an institute in the Syrian Arab Republic or another Arab country will be too costly unless costs and benefits are spread to the others.

The third question is that when you spoke about composites you mentioned the word transport. Now, I do not think we have a big transport industry at the moment. We use vehicles to a great extent, and we spend a great deal on them, but we do not have car industries where we can introduce composites. I think the food industry would be a better subject to go into, but we need the plastic for the greenhouses; we need the hoses, the drip systems, packaging, and other things. I wonder if we can also give priority to the food industry. I agree with the ceramics, electronics, and so on, but in the transport industry I do not think we can do very much. The question, therefore, is: in which industry can we achieve something?

Mr. Suham Al-Madfai:

Q. I raised this question yesterday, and I asked one of our colleagues from the West, but no answer was given. It is natural that nobody gives free information concerning something on which a great deal of money and time and effort have been spent; this is expected. However, there is a certain level of knowledge in technology that is available that could be used at least to a certain degree, and the rest can be made up. We should have our own R&D effort in the region or in the country.

My second point is that international organizations such as UNIDO and others could help greatly to solve this problem; at least they can help us direct our work.

Mr. O. Bizri:

Ans. I am very glad that you have brought up some of the issues, although they are dealt with one way or another in the paper. At the moment, we do not have in the Syrian Arab Republic a science and technology policy. To start with Mr. Derwish's question, we do not have a Syrian science and technology policy as such, so that in itself is a tremendous handicap. To have a materials science and technology policy or even a materials policy is quite an undertaking. Now, what is to be done in such a case? Does one wait until there is a national science and technology policy before doing anything? It seems to me that the most logical course of action, the most practical one, is to adopt a partial but flexible science and technology policy with the hope of integrating them at a later date, as long as they are based upon proper intelligence and a proper assessment of technology. This is the way to act. Otherwise, one has to sit and wait for someone to come and formulate an overall science and technology policy. That, I hope, answers your question to some extent.

As far as R&D manpower is concerned, if you would like to have figures, for instance, the personnel in HIAST and SSRC total around 600 engineers and university graduates, 150 Ph.D. holders and about 900 technicians. They are dispersed in a number of departments, including electronics, chemistry, biology, etc., six or seven departments. However, one has to remember that the electronics industry in Israel itself employs about 32,000 scientists of all grades, excluding technicians. This is quite a difference. As far as ceramics are concerned, you are quite right; we do not have any activity in the area of ceramics apart from their use in some electronics applications as a substrate for electronic circuits. The ceramics there are imported, of course. Nevertheless, it means that we would be interested in joint efforts to understand more about ceramics and manufacture some ceramics. This is definitely in the cards, and could be discussed further.

Coming now to Mr. Dajani's points, I agree that at a certain level the science and technology of materials are inseparable; but when you want to look at R&D efforts, when you want to solve technical and scientific problems related to materials, I think it is also permissible to look at a subpolicy or a substrategy. It is only from that point of view, and in order not to get involved in protracted economic and political arguments, that it is advisable to concentrate on science and technology issues. This, in fact, is the reason why the separation has been made. Now when we wrote this paper, we were actually thinking at the regional level. We only mentioned certain elements in a national policy for the science and technology of materials which we knew best. At the end of the paper, if you would like to see page 26, for example, we do have a proposal which we have been developing with UNIDO for setting up a regional centre for new materials research and development. In appendix II, I have included informal notes on the establishment of that centre. There are several points I could not go into for lack of time. But the paper deals with a number of regional considerations, such as cooperation. As you mentioned quite rightly, you cannot do serious scientific work in new materials without investing quite heavily in diagnostic and analytical equipment, and to do that single-handedly I think would be quite prohibitive.

Transport was chosen not because we are manufacturers of vehicles of any kind, you are quite right, but if you have followed developments in the transport industry in recent years, you are aware that in many cases you can enter the market mainly as a producer of a particular set of parts. Now since some of the Arab countries are situated on top of a huge sea of oil, it is not inconceivable for them to develop products based on the oil that they have as a raw material, and develop the capabilities for manufacturing certain parts. I think this may be looked into, but I agree that the food industry is quite an important sector and should not be neglected at all. Again, I agree with Mr. Al-Madfai's points, and that covers most of the questions.

PART FOUR

MATERIALS TECHNOLOGY: THE CHALLENGES FACING ESCWA COUNTRIES

Antoine Zahlan

The ESCWA member countries today face the challenge of acquiring the capacity to design, produce and utilize traditional and advanced materials at an international level of competitiveness. This challenge is analysed below. The objective is to identify in detail the policies and measures that must be adopted in order to acquire the technological capabilities essential to support a profitable, modern and internationally competitive materials industry in the region.

The challenge is twofold: the ESCWA member countries are richly endowed with raw materials that provide the foundation for world-class industry; however, these raw materials are of limited use without the R&D support and policies necessary in order to convert them into the new materials for the world economy of the next century. Therefore, industrialists and planners in the public and private sectors are called upon to pursue policies that will lead to the efficient transfer of technologies as an integral part of procurement and industrialization programmes. Secondly, those responsible for education, research and research funding, information, consulting, and contracting must be aware of creeping obsolescence, of the possible marginality of their operations, and of the isolation of their institutions. Thus, those responsible for these threatened institutions must seek to upgrade and integrate their respective activities if they are to assume a useful role in the development of a national MSE capability.

The role and characteristics of advanced materials will be discussed at length in the papers presented to the workshop which has been organized on this subject. The remarks made in the present document relate to the implications for the ESCWA member countries.

The ESCWA member countries are already a major importer of advanced materials as components of airplanes, automobiles and computers as well as industrial and military equipment. Industries in the ESCWA region produce a wide range of materials, and a variety of technologies that utilize advanced materials are being considered for large-scale applications in a number of ESCWA member countries. It is thus important that research teams and institutions capable of offering accurate advice and support become available in the ESCWA member countries as soon as possible.

A. *Implications for the socio-economic development of the ESCWA member countries*

Advances in materials science and technology present extensive implications for the region. New materials drive traditional ones out of the market, and they create demand. Materials science could also provide the basis for a sound and profitable diversification of the economies of the ESCWA member States.

The high rate of technology change imposes a close relationship between the supply and demand for scientific and technical expertise. To facilitate the analysis and discussion, it is thus useful to group the issues and challenges that confront the ESCWA member countries into two broad categories:

(a) The demand side or those parties in the ESCWA member countries that utilize materials technologies;

(b) The supply side or those parties in the ESCWA member countries that stand to develop and support a materials industry.

The establishment of a profitable and successful materials industry is contingent upon an effective relationship between the demand and supply sides.

The approach adopted here aims to identify the prime movers on both the demand and supply sides. The policies of these prime movers are of capital importance to the development of a materials industry: unless their policies converge on common objectives, it is difficult to move ahead in the domain of materials science and engineering.

B. *The demand side*

The demand side consists of those who procure the products of advanced and traditional materials[1] from foreign markets as well as those who use and/or manufacture them. Procurement practices and policies may be utilized to stimulate the development of local technological capabilities. Thus, the major importers of advanced products (such as the national airline, the military, hospitals and telecommunications organizations) could assume a constructive role in the process of promoting national materials industries.

Each of the major traditional- and new-materials industries, such as cement, phosphates, iron and steel, petrochemicals and textiles, could serve as a major centre for the development of local capabilities in MSE. The most effective way to promote the development of advanced-materials industries in the ESCWA member countries would be for existing and future investors to pay due attention to the technological content of their investments. It is thus useful at this point to enumerate the various parties in the ESCWA member countries who are or may become directly involved in the procurement, use or production of advanced materials or all three.

1. *Trade and procurement*

The economies of the ESCWA countries depend heavily on the importation of consumer products, capital and military goods and professional services. It should be possible to analyse imports of all these products and services to ESCWA member countries with a view to optimizing imports and to identifying practical, profitable and feasible products that may be manufactured locally.

Needless to say, all products should be manufactured with the export market in mind. Given the professional and natural-resource base of the Arab States, such an analytical effort should yield prompt returns.

The first step may be oriented to optimize procurement; in other words, to reduce the cost of imports and to select the most relevant materials and to use imports in the most effective

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[1] It is important to bear in mind the significance of traditional materials as the foundation for the development of advanced-materials industries.

manner. The optimization of procurement involves the analysis of each major contract in order to ensure the following:

(a) Optimization of the selection of materials;

(b) Unpackaging of the technology being imported;

(c) Adoption of the relevant technical standards;

(d) Establishment of testing services;

(e) Acquisition of operational, servicing and repair capabilities from the suppliers.

Each of the above-mentioned activities, if properly acquired, could transfer valuable technologies to the ESCWA member countries. Technical studies should be undertaken on imported items to identify those that may be already produced in one or more ESCWA member country and those that could be profitably manufactured locally. Local manufacturing could be undertaken through joint ventures, under licence or even by foreign firms attracted to the region.

It is necessary to create effective communication channels between importers and industrialists; otherwise, opportunities provided by current procurement strategies cannot be translated into profitable investments. The communication channels between different economic organizations in the same country and in different countries are presently very weak; it is important to improve communication between the various parties that constitute the demand side.

2. *Industry*

Arab industrial exporters compete with firms from other countries and are involved directly and indirectly with advances in materials. The development of new industries in the ESCWA member countries involves the manufacturing of advanced materials and/or the use of advanced materials in the manufacturing process. It is thus essential that these industries acquire capabilities in materials science and engineering.

Industrial firms are directly and indirectly involved in the production, import and export of capital goods and materials. Industry is the natural leader, the prime mover, of a genuine movement towards the establishment of materials industries. Industry has the resources to provide the momentum for developing MSE capabilities.

The globalization of industrial production means that a successful industrial strategy must be prepared to compete in an international market. Thus, industrial firms in the ESCWA region must consider how to improve the quality and performance of their products and how to reduce the cost of production.

The interdependence between industrial development and new materials has already been stressed. For example, a number of ESCWA member countries have established partial automotive industries; however, most of the automotive technologies now in use in the region are obsolete. Moreover, the manufactured cars are below international quality standards and are often more expensive to make than imported cars. Nevertheless, some firms are considering the upgrade and expansion of their automotive industries.

New materials are expected to influence the design and manufacturing of cars in the near future. New-car engines are expected to be partly or wholly made from ceramics. The efficiency of ceramic engines is expected to be considerably higher than that of metal engines, the reason being that ceramic engines allow a higher temperature. The manufacturing processes and the raw materials required for a ceramic engine are completely different from those required in the case of a steel/aluminium engine. Composites are also expected to have a major impact on the design and manufacturing of car bodies.

Thus, the very future of an automotive industry is contingent upon the development of capabilities in new materials. The same type of consideration applies to almost every major industrial product. It is thus impossible to consider industrialization in a serious manner without paying adequate attention to MSE.

(a) *Petroleum-based materials*

The fact that the ESCWA region possesses enormous resources of oil and gas is not in itself an advantage; many producers of advanced materials and chemicals are not gas or oil producers. However, the possession of these natural resources should induce an interest in building a diversified economic base.

The trend to establish heavy petrochemical industries in the ESCWA member countries is well established. Bulk chemicals add little value. Value-added is commensurate with the technical inputs built into the manufacturing process.

Composite materials involving carbon fibres, polymers and plastics are derived from oil and gas and represent high value added.

(b) *Engineering industries*

New materials are having a massive impact on engineering industries, both in terms of the products manufactured and also in terms of the processes utilized. There is an increase in the use of special alloys, plastics, composite materials, carbon fibres and ceramics. ESCWA member countries have made considerable investments in engineering industries; although these industries are still in their infancy, advanced materials are vital for their survival.

(c) *Metallurgical industries*

ESCWA member countries have invested heavily in iron and steel industries. There are considerable opportunities for specialization in selected alloys and special steels. Special alloys and high-strength steel assume an important role in engineering industries. However, efforts to establish engineering industries in the ESCWA member countries have not borne fruit. The major obstacle has been the turnkey technology policies that are still in vogue in the region.

(d) *Construction materials*

ESCWA member countries are major producers and consumers of construction materials (such as cement, brick and ceramics), and the manufacturing facilities to produce these materials have all been imported. These traditional-materials industries have witnessed much progress in both their processes and products in recent years. With an annual turnover exceeding $100 billion, construction is the largest economic activity in the ESCWA member countries.

There are constant advances in the processes and the types of construction materials and methods of use. Because of the scale and economic importance of the construction industry, manufacturers of construction materials could assume an important role in the development of MSE in the ESCWA member countries.

(e) *Medical applications*

Hospitals and surgeons are important consumers of biomaterials, expensive materials whose importation and use call for high standards of manufacturing, high skills in use and application, and high standards in testing. There is considerable scope here for cooperation between industrialists and the medical profession.

(f) *Aerospace, transport, telecommunications and others*

ESCWA member countries are massive importers of products in all of the above-mentioned sectors. These industries offer a wide range of challenges and opportunities for Arab cooperation to manufacture a large variety of inputs. For example, the ESCWA member countries could start by adopting the practice of many of the major airlines: purchasing airplanes stripped down and manufacturing the furniture and avionics locally. Slowly, these efforts could be expanded to include parts or all of the engines, and parts or all of the plane's body. The production of all these materials could be undertaken in joint ventures, with direct foreign investment or under licensing. Each one of these products could initiate an important industrial activity.

Naturally, it would not be economical if all the materials required for such manufacturing were to be imported; the focus must be on producing much of the supplies locally and trading their export against the purchase of hardware that is not manufactured locally. Arab trade strategy could be directed toward promoting the transfer of technologies with respect to specific products.

3. *Potential demand and implications*

The upgrading and modernization of existing industries, as well as the development of new industries, in the ESCWA member countries necessarily implies a profound involvement with advanced materials. A few examples will be presented to illustrate the challenges and opportunities.

Catalysts, minerals, power production and transfer illustrate the range of involvement of advanced materials that may have a bright future in the ESCWA member countries. Other illustrations, such as the likely impact of developments in ceramics and composites on the automotive industry, have already been mentioned.

The motivation for the development of an industrial base to manufacture catalysts and superconductors could be provided by the chemical and electric-power industries. The ESCWA member countries are world-scale producers of oil, gas and petrochemical products; the above-mentioned chemical industries are heavy users of catalysts, which are expensive advanced materials. The development of the catalyst industry falls within the framework of an advanced materials industry and would be a very sensible objective. The development of an integrated Arab electric-power industry and efficient, inter-urban and inter-State transport system could also have considerable impact on the emergence of a market for superconductors.

A catalyst industry could, in turn, have an enormous impact on the development of mining of rare earths and the development of a number of other support activities. For example, the ESCWA member countries have important deposits of rare-earth minerals as well as a large variety of other ores which could be used to produce inputs for indigenous catalyst, superconducting and materials industries. The exploitation of these mineral resources would require considerable technical developments in geological sciences, mining technologies, chemistry and chemical engineering.

The development of a modern power-grid system and a rapid transport system may require the extensive utilization of superconductors, which, in turn, provide markets for rare-earth elements. Although the solution of these large-scale problems may still be in the future, likely demand should at least stimulate the establishment of core scientific and engineering research teams.

4. *Professional services*

Professional services are treated extensively under the supply side in the following section. It is important, however, to mention them here because they straddle the supply and demand sides. In fact, they provide the critical linkages between the two sides. Without these services, it is difficult to find ways to integrate the activities of an economy. In other words, professional services provide the integrative mechanisms within an economy.

Consulting, contracting, testing, training and other technical services assume critical roles in investment and in industrial production. Much technological acquisition and accumulation takes place in organizations that provide professional services. As the ESCWA member countries import and use increasing amounts of new materials and processes involving new materials, professional services must be capable of providing the necessary support.

Very few major firms in the ESCWA member countries have adopted an R&D programme to support their industrial strategy. This has left industrial firms in the ESCWA member countries in a vulnerable position. Currently, there are signs of changes in policy in some ESCWA member countries. For example, SABIC (Saudi Arabian Basic Industries Corporation) recently (1991) adopted a programme to develop in-house R&D capabilities at 1 to 30% of its turnover. This effort is also supported by the Saudi Arabian Government through the King Abdul Aziz City of Science and Technology (KAST). One also finds similar efforts in Iraq and a few other Arab countries, but these efforts are still on a very limited scale and they are all of recent origin.

C. *Supply side*

The supply side of the equation encompasses those activities that are essential to MSE and that are related to: the supply of professional and technical manpower; research in materials science; technical training and continuing education; information services; standards and quality control services.

Most of the activities on the supply side are major components of the science and technology system of a country. These activities provide the essential infrastructure for any effective and viable science-based activity.

1. *Prevailing educational and scientific infrastructure in the ESCWA member countries*

Professional manpower is a major input in MSE. Thus, the supply of such manpower is an important factor in any MSE strategy. The following is a brief account of the availability of such manpower in the ESCWA member countries.

Comprehensive and up-to-date coverage of higher education and R&D activity in the ESCWA member countries is rarely available on a systematic basis. In fact, the most recent such survey dates from 1986 and covers only 1984. Below is a brief presentation of the results of the survey, undertaken within the framework of the ALECSO programme[2,3] and supplemented with more up-to-date data whenever possible. (The findings of the ALECSO study relate to all Arab countries and not only those covered by ESCWA.)

By 1984, the Arab countries had established some 81 universities. These had an enrolment of 1.5 million students. Enrolment in two-year, post-secondary programmes amounted to an additional 262,000 students, and the doubling time was seven years. Since then, the rate of growth of enrolment in some Arab countries, such as Egypt, has become negative as a result of deliberate government policy. Nevertheless, one should expect to find about 3 million students enroled in institutions of post-secondary education in 1992.

The proportion of the 20-24 age group enroled in post-secondary education was 10% (1984) and 12% (1988) for the entire Arab world. (By comparison the EEC average is 14%.) In individual Arab countries, this proportion was: 37% for Jordan (the highest in 1985); 16 to 18% each in Egypt, Qatar and the Syrian Arab Republic; and below 5% in the Sudan, the People's Democratic Republic of Yemen and the Yemen Arab Republic,[4] Mauritania and the

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[2] *A Strategy for the Development of Science and Technology in the Arab Nation: The General Report and the Sectoral Strategies* (ALECSO Committee for the Development of a Strategy for Science and Technology in the Arab Nation), published by the Centre for Arab Unity Studies (Beirut, 1989), p. 642 (in Arabic; also available in English).

[3] For the list of references, see page 475.

[4] The two countries merged to form a single State on 22 May 1990.

United Arab Emirates. The percentage of university students enroled in the applied and basic sciences is 40 to 50%.

In 1985 there were 28,155 professors in the 81 Arab universities with a Ph.D. degree and an additional 23,055 with an M.S. The distribution of the 28,155 Ph.D. professors is shown in the table at right.

Agriculture	3 696
Basic sciences	5 116
Economics and management	4 019
Engineering sciences	1 854
Humanities	7 413
Medical sciences	6 057
TOTAL	28,155

The number of professors has been increasing annually at a rate of 10%; thus the number of professors should have doubled by 1992.

In addition to those studying in national universities, there are about 150,000 to 250,000 Arab students enroled in institutions outside the Arab world. Accurate statistics on international education are not available, thus the uncertainties in these numbers. A large proportion (in excess of 70%) of students outside the Arab countries are enroled in post-graduate studies leading to an M.S. or Ph.D. degree. Seventy per cent of Arab students in the United Kingdom are enroled in post-graduate study.

This substantial effort has naturally led to the education of large numbers of young Arabs in virtually all fields of knowledge. A brief account of the number of Arab engineers may give an idea of the scale of these educational efforts. In 1984, there were 56 colleges in the Arab countries that offered a four-year programme in engineering. These enroled 173,000 students and graduated 26,629 B.S. engineers in that year. The number of graduates in the various fields of engineering from national universities between 1985 and 1990 exceeded 160,000. In 1984, 88% of all engineering students were enroled in Algeria, Egypt (which had 40%), Iraq, Saudi Arabia and the Syrian Arab Republic. Since then, the decline in university enrolment in Egypt and the expansion in other countries should have changed this ratio.

No accurate or detailed statistics on the number of engineers in the Arab countries are available. At the 1989 meeting of the Federation of Arab Engineers held in Kuwait, the President of the Federation stated that there were 600,000 engineers in the Arab countries. This is a large and significant number: there were 1.4 million engineers in the United States in 1986. American universities graduate 80,000 engineers annually compared with 26,000 (in 1985) from Arab universities. If the rate of growth of enrolment of engineering students continues at current rates, Arab universities are expected to graduate more than 80,000 engineers annually by the end of the century.

The output of Arab universities in the sciences is also large and growing. Arab universities graduated 18,849 B.S. holders in the basic sciences.

It is thus clear that the Arab countries have access to a large and increasing supply of professional manpower in practically all fields of science and engineering. Large numbers (on the order of a few thousand per year) earn the Ph.D. degrees in various fields of science and engineering in OECD countries. There is little doubt about the abundance of professional manpower; in fact, the lack of suitable employment opportunities has induced a substantial brain drain.

Arab universities have not paid much attention in their curricula to the formation of scientists and technologists in the materials sciences. Universities have generally emphasized the training of engineers in traditional areas such as civil and mechanical engineering. Chemistry and physics departments have also generally offered broad curricula with little specialization in solid state physics, polymer sciences, plastics, metallurgical sciences and so on.

Consequently, the Arab countries have not sought to build an industrial or professional infrastructure in materials sciences. This simple fact must be kept in mind when operational and practical measures in this field are discussed. It must be recognized that the region is at the beginning of a long development process, and considerable efforts and investments are required to establish university-level curricula and programmes.

2. *Institutional development*

Scientific and technical manpower must be organized in specialized institutions and industries before it can yield useful economic returns. It is not sufficient, therefore, to train and educate; it is necessary to adopt appropriate policies and measures to encourage the formation of the organizations that are essential to the application of technology. These organizations are: consulting firms; contracting firms; industrial firms; and R&D institutions.

(a) *Consulting firms*

These firms undertake the design of buildings, civil works and industrial and process-engineering plants. Given the appropriate economic and technological policies, national consulting firms could assume a crucial role in establishing intersectoral relationships as well as forward and backward linkages. During the past 20 years, entrepreneurs in the Arab countries have established several thousand consulting firms mostly specialized in basic and small-scale civil engineering. The overwhelming emphasis has been on civil engineering because of the substantial local markets for civil engineering services in the home-construction industry.

Governments in the Arab countries have not adopted technology or economic policies that favour the acquisition and accumulation of technology by national firms. Industrial consulting contracts are awarded to foreign firms with no provision for serious technology transfer. This situation has deprived the region of enormous opportunities for technology transfer.[5]

Consulting firms provide important linkages among, *inter alia*, R&D organizations and universities as regards standards, policy-making, education and social and political awareness of technical change. Consultants specify the materials and equipment required for a particular

[5] A.B. Zahlan, *Acquiring Technological Capacity: A Study of Arab Consulting and Contracting Firms*, Macmillan (London, 1991). (Also published in Arabic by the Centre for Arab Unity Studies, Beirut, 1991.)

installation, whether it is a building, a highway or an industrial plant. Thus, they assume an important role in influencing procurement.

It is to be expected that dependence on foreign consulting services marginalizes academic, research and industrial systems. Furthermore, so long as professional institutions are not involved in the analysis and planning required by a project, there will be little participation in option analysis and project assessment. The externalization of the consulting process also means that the community would not be aware of the technological implications of its investment programmes. Thus, planners are unable to identify promising materials or to design suitable policies and programmes for the production of materials and products that have a particular economic, social or political value.

(b) *Contractors*

Contractors undertake the actual construction of all facilities, ranging from roads to nuclear plants. There are about 100,000 Arab contracting firms in the Arab countries. Of these, about 100 have substantial capabilities, with an annual turnover in excess of $100 million each; another 100 may have an annual turnover in excess of $300 million. The value of the Arab construction market is about $100 billion per year, and the Arab contractors' share of this market is about 50%.

The public policies of the Arab countries in the technological, labour, financial and insurance domains have not promoted the development of Arab contractors. The absence of policies favouring the acquisition and accumulation of technology has made it very difficult for national firms to develop corporate structures or to build capabilities in industrial construction. Arab contractors have maintained a task-force type of organization. This is not very conducive to the acquisition and accumulation of industrial technology. Thus, even the largest Arab contractors specialize in civil-engineering technologies. Contractors are also responsible for R&D: a key function for optimal economic cooperation between industrial facilities.[6]

(c) *Industry*

Manufacturing and information industries account for the bulk of economic activity in a modern economy. These are the firms that design and manufacture all capital and consumer equipment (such as automobiles, airplanes, pumps and factories); explore for, produce, process, transport and market oil and gas; and so on.

In the Arab countries, investments in industrial plants during the past two decades constituted 21% of gross fixed capital formation (GFCF); an additional 10% of GFCF was invested in power generation and distribution; transport and communications attracted another 14% of GFCF. These investments add up to some $900 billion.

The national oil and chemical companies in the Arab countries are similar to those in industrial countries. However, Arab firms have generally opted for the turnkey approach and resisted the pursuit of national and regional technological roles. The emergence of serious MSE

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[6] Ibid.

capabilities in the Arab countries cannot be envisaged unless the existing islands of industrial activity extend support to local institutions and organizations to cooperate in the development of national expertise. The bridge between supply and demand must be constructed, and industry is the prime mover to undertake such a vital task.

3. *Scientific research*

Research activity falls into two broad categories: basic and applied. The usual distinction is that basic research may or may not have an application in the immediate future. As it turns out, it is very difficult to draw sharp lines between the two. Many areas of mathematics, biology, electronics, materials sciences and optics which were considered to fall in the basic science area a few years ago have been found to have important and immediate applications. Similarly, many technologies have made significant contributions to the development of the basic sciences.

Universities in the Arab countries have been, and still are, the leading centres for scientific work in both the basic and applied fields. The number of institutions that have published one or more scientific papers increased from 289 in 1977 to 407 in 1983 and 708 in 1989, an annual growth rate of 8%.

In 1983, researchers in the Arab countries published a total of 2,612 articles in refereed journals of international standing. By 1989, this number had risen to 5,043. In 1983, 48% of all Arab output came from 12 institutions, each of which had published 50 or more papers. Out of the 12 institutions, 11 were universities; the remaining one was the National Research Centre (NRC) in Cairo. The predominance of universities was sustained in 1989: the NRC published 144 papers, and the Kuwait Institute for Scientific Research published 49, while Kuwait University published 356.

During the 1970s, the published output from the Arab countries doubled every six years; the rate of growth appears to be slowing down slightly, and the doubling time is now closer to seven years. Between 1967 and 1983, the Egyptian share of Arab output decreased from 60% to 30% despite a steady expansion in the actual Egyptian output; but in 1989, the Egyptian share of Arab output increased to 39%. The share of the oil-producing countries (Algeria, Bahrain, Iraq, Kuwait, the Libyan Arab Jamahiriya, Qatar, Saudi Arabia) increased from 14% in 1967 to 41% in 1989. In 1990, scientists in Saudi Arabia published 20% of all Arab output, and the bulk of the output from oil producers comes from Kuwait and Saudi Arabia. Kuwait University was the second largest producer in the Arab world in 1989; a close second after Cairo University. In 1990, Kuwait University was the leading publishing institution in the Arab world. As can be seen from table 1, the performance of several Arab countries continues to be disappointingly weak.

The scientific output of various countries per million inhabitants can be compared on the basis of the compilations of ISI on publications in refereed journals. During the early 1980s, the number of such publications per million inhabitants was as follows: 1,020 in the United States, 450 in France, 18 in Brazil, 16 in India and 15 in the Arab countries. The Arab countries were near the top of the third-world level of activity, but by 1989 the relative position of the Arab countries with respect to Brazil had declined slightly, while with respect to India it had improved slightly. The Arab countries publish at the same level as India and Brazil,

Table 1. SCIENTIFIC PUBLICATIONS FROM THE ARAB COUNTRIES IN INTERNATIONAL JOURNALS, 1989

Country	Number of publications	Number of publishing institutions	Output of larged publishing institutions
Algeria	130	82	Constantinue U: 14
Bahrain	70	11	Bahrain U: 49
Egypt	1955	165	Cairo U: 377
Iraq	348	48	Baghdad U: 66
Jordan	251	29	Jordan U: 93
Kuwait	540	48	Kuwait U: 356
Lebanon	70	7	AUB: 49
Libyan Arab Jamahiriya	60	18	Al Fateh U: 14
Morocco	197	65	Rabat U: 40
Qatar	51	9	Qatar U: 28
Saudi Arabia	919	96	King Saud U: 254
Sudan	135	32	Khartoum U: 83
Syrian Arab Republic	42	12	ICARDA: 19
Tunisia	212	62	Tunis U: 69
United Arab Emirates	40	17	UAE U: 18
Yemen	23	7	Sana'a U: 18
	5 043	708	

Source: Institute for Scientific Research, *Current Bibliographic Directory of the Arts and Sciences*, Philadelphia, 1989.

which is roughly 2 to 5% of OECD countries, but this level of publication is not adequate to support the serious development of science-based industries.

The diffusion of scientific knowledge and research expertise within the Arab countries is slower than in Brazil and India. Thus, although these regions publish equal amounts on a per capita basis, the extent to which scientific output is utilized within each region varies considerably.

There were about 250 R&D centres in the Arab countries in 1985. Half of these were engaged in research in agriculture, nutrition, water and irrigation, marine sciences and the biological sciences; 14 (6%) were involved in solar energy; 9 (4%) in oil and petrochemicals; 11 (4%) in ecology; and 11 (4%) in the basic and computer sciences.

In 1984, these R&D centres employed 3,745 Ph.D. and 4,378 M.S. scientists and engineers. There were 1.7 researchers outside the university (2.7 if the university research workers had been included) in the Arab countries per 10,000 economically active manpower; by contrast the number was 99 for the former USSR, 66 for the United States, 58 for Japan, 39 for France and 36 for the United Kingdom.

Research activity in the Arab countries is strongly directed towards applied subjects, with considerable emphasis on medicine and agriculture: 38% of total published output is in medicine; 20% in agriculture; 17% in engineering; 17% in basic science; and 8% in economics and management. The most common research areas are agronomy, food technology, nutrition, general and internal medicine, general biomedical research, pharmacy, ecology, remote sensing and water resources.

Despite the valiant effort of a number of scientists, basic scientific research is on such a small scale that it can be considered as virtually non-existent.

Because of the extensive dependence of Arab countries on foreign suppliers of technology and services, the national R&D capabilities required to support and service various economic sectors have not developed fully. In other words, the roles that research and development organizations assume in planning, designing and operating economic installations have been severely constrained.

During the past few years, USAID (United States Agency for International Development) programmes in Egypt have supported the Academy of Research and Technology to develop a programme focused on solving specific problems through the promotion of research/industry linkages. Although on a modest scale, this programme is proving to be successful: 40 technical projects are supported annually. The Egyptian managers hope that the programme will become self-sustaining in the near future. At the moment, USAID covers the cost of the foreign-exchange requirements of the projects.

The Governments of Algeria, Iraq and Saudi Arabia have also adopted programmes to promote research/industry cooperation. Despite all these efforts, the linkages between R&D institutions and consumers of their services are still weak; much more must be undertaken before a more satisfactory state of affairs is attained.

Accurate figures on the financing of R&D in the Arab countries are difficult to obtain. According to the ALECSO survey of 1986, the Arab countries devote only 0.2% of their GNP to R&D. Table 2 is based on UNESCO statistics, and the figures quoted are at variance with those of the ALECSO survey. Figures for Asian and Latin American countries fall near those of the Arab countries. On a per capita basis, the Arab countries rate at the same level as other developing countries.

Table 2. SCIENTISTS AND ENGINEERS ENGAGED IN R&D AND EXPENDITURE FOR R&D

Area	Year	R and D of scientists and engineers		R and D (millions of US dollars)	Expenditure as percentage of GNP
		Number	No/month		
Arab countries	1980	51 472	330	3 824	0.94
	1985	61 268	336	3 465	0.94
	1990	77 261	363	3 078	0.76
Asia (excluding Arab countries)	1980	758 533	304	28 199	1.41
	1985	920 763	336	44 024	1.80
	1990	1 190 369	396	88 533	2.08
Latin America	1980	86 901	242	3 635	0.44
	1985	125 395	312	3 062	0.43
	1990	162 930	364	2 860	0.40

Source: UNESCO Statistics.

Thus, the absence of large-scale R&D in the Arab countries contributes to the weak capacity to respond to the challenges posed by developments in materials science.

The Republic of Korea and Taiwan Province of China are among the few developing countries which are adopting ambitious research programmes in advanced materials. Although autarky is impossible even among industrial countries, a strong R&D base is essential to enable national firms and organizations to be aware of international scientific developments and to make intelligent decisions concerning investments and technology selection. In both the Republic of Korea and Taiwan Province of China, the emphasis is on materials synthesis and processing.[7]

(a) *MSE R&D*

In order to assess the availability of Arab scientific manpower and research output in the general area of materials science, about 10 international periodicals in this field were examined. This is, of course, not a comprehensive survey, but it should be seen as an indication of the present state of affairs.

[7] "Final Report of the Expert Group Meeting on Materials Policy Issues", UNIDO National Materials Policy Project, TIFAC/Department of Science and Technology, Bangalore, India, 11-13 December 1991, UNIDO, July 1992.

It is not surprising to find Arab scientists on the editorial boards of these international periodicals (roughly 1 out of 30 editors of several scientific periodicals is an Arab expatriate); roughly 1 to 5% of the articles that appeared in these periodicals during 1990 and 1991 were authored by Arabs. In one particular periodical, 6 out of 27 papers that appeared during 1990 were authored by Arabs: three from Iraq, two from Egypt and one from an Arab scientist in the United Kingdom.

The contributions from institutions in the Arab countries were concerned with research on traditional materials. The scientists in the Arab countries were based in departments of physics, chemistry and mechanical engineering at several national universities, mainly in Lebanon, Iraq, Egypt, Saudi Arabia, or national research laboratories (such as the National Research Centre in Cairo; the Petroleum Research Centre in Basrah, the National Institute for Standards in Cairo, the National Centre for Radiation Research and Technology in Cairo, and the Kuwait Institute for Scientific Research).

Some of the contributions were the result of collaborative work between visiting Arab scientists in European, Japanese and American institutions, others were the result of work performed in Arab institutions, and still others came from young scientists who undertook the work as part of their doctorate research. All of this variety is a healthy sign, for it shows that the Arab scientific community is now substantial and is already circulating worldwide.

D. *Implications for MSE*

It is useful to summarize the findings presented in section B in tabular form in order to highlight their implications for actual and anticipated MSE activity in the Arab countries. Nine MSE aspects have been selected for emphasis. The entry in the first column of table 3 is that aspect of MSE that needs urgent attention; the second column defines the causes of difficulty. For example, multidisciplinarity is vital to MSE activity. The difficulty is that the R&D in the Arab countries is fragmented, and institutional regulations act to limit multidisciplinary R&D and teaching. The last column lists the types of actions that are required to overcome the difficulty. In the case of multidisciplinarity, the obvious action required is to promote multidisciplinarity in R&D.

Each of the difficulties that have been identified calls for a particular response. Some of the responses are on the national level, others are on the regional and international levels. Furthermore, the nature of the responses vary: some are scientific in nature, while others are economic, political, institutional or legal.

E. *Recommendations*

The recommendations presented in this section take into consideration the efforts to date with a view to proposing cost-effective and relatively simple and feasible measures which should initiate a self-adaptive process. A basic objective of sections E and F is to stimulate discussion at the workshop in order to generate recommendations from the participants.

The Arab countries have already made considerable efforts towards the education of professional manpower without reaping the fruits of this effort. It is clear from the information presented that the Arab countries have achieved considerable success in the education of large

Table 3. Summary of MSE implications

MSE aspect	Difficulty	Required action
Multidisciplinarity	R and D in Arab countries is weak in multidisciplinarity.	Promotion of multi-disciplinary R and D.
R and D base	Underdeveloped; low % GNP devoted to R and D.	Large R and D manpower available at home and abroad; mobilization possible.
Planning capabilities	i. Bureaucratic; ii. Rigid; iii. Excessive red tape; iv. Slow rate of change.	i. Place scientists and professionals in control of planning; ii. Reduce rigidity through elimination of bureaucrats; iii. Provide R and D funds.
Cooperation: industry/R and D/ university	Very limited	Promote cooperation through standard measures.
Networking of Scientists	Very limited.	Promote through the dissemination of information and travel funds.

Table 3. (*continued*)

MSE aspect	Difficulty	Required action
TT between Arab countries	Very limited. Lack of information on R and D, and weak networking among scientists.	Promote TT through: i. Generation and dissemination of information; ii. Organization of professional and business meetings.
TT with foreign countries	Very limited.	Promote TT through: i. Technology unpackaging; ii. Utilization of local CEDO's; iii. Participation of Arab scientists in international MSE.
Procurement	Arab countries import black boxes.	Arab countries have estimated technological capacity of 80 to 85 per cent of demand. Proper policies and procedures should reduce dependence on imports from 100 per cent to 10-15 per cent

Table 3. *(continued)*

MSE aspect	Difficulty	Required action
		of present levels with possibility of further reductions in due course.
Demand for MSE	Demand is high, but Arab market is highly segmented geographically and institutionally.	Use of national CEDOs combined with unpackaging and networking of scientists may promote the conversion of demand into a powerful economic force.

numbers of scientists and engineers. Although a large number of R&D centres have been established, these institutions have not been supported to the requisite level, nor have they been integrated into the economy. Arab R&D centres have remained marginal, primarily because of the technology policies adopted by their respective Governments.

It would be counter-productive to pursue long-term policies before the adoption of basic measures to utilize existing resources optimally. Thus, the proposed recommendations stress overcoming the existing state of rigidity, disaggregation and isolation of the science and technology system in the Arab countries. Once this is accomplished, it should become easier to develop more complex and ambitious policies.

Arab countries have invested heavily in the establishment of a substantial industrial infrastructure worth some $800 billion. These are not part of a technological structure, since they have been acquired through technology-free, turnkey contracts. There is thus a very extensive, disjointed foundation of isolated manpower, resources and industries. The main challenge that the Arab countries now face revolves around bringing about an integration of these substantial resources into a coherent whole.

The fact that the annual gross fixed capital formation of the Arab countries exceeds $100 billion should facilitate the implementation of a coherent programme. In other words, the main focus should be on designing and implementing new policies rather than providing more professional manpower, industrial facilities or new capital for investment.

The rest of this section will be devoted to presenting and discussing practical, low-cost and effective measures that, if adopted, may bring about the desired outcomes. The following recommendations aim to:

(a) Make information widely available on existing resources and economic planning in order to facilitate communication and cooperation between interested parties;

(b) Support the compilation and dissemination of accurate and timely information on MSE in the Arab countries and abroad;

(c) Induce systematic cooperation among industries, universities, professional societies, consulting firms, contractors, financial institutions, testing and quality control agencies;

(d) Assist leading scientists to expand their research activities;

(e) Develop effective methods for prioritizing objectives on rational grounds;

(f) Reduce the excessive control of bureaucrats over programming of R&D activity and enhance the role of scientists, engineers and industrialists in all aspects of planning.

Recommendation 1: identification and networking of national capabilities in MSE

The Arab countries have considerable resources, manpower and capital investment in productive industries. What is required is the integration of these capabilities into a functioning system of relationships with a focus on materials science. The objective of this recommendation is to promote the conversion of existing disjointed potentialities into effective and substantial MSE capabilities. There are numerous ways to realize prompt optimization of the existing, incoherent set of isolated non-interacting subsystems.

The first step must consist of compiling accurate and timely information and establishing information flows and communication channels. MSE research activity is already taking place in several Arab institutions, but there is limited communication between the scientists and engineers undertaking this activity on the one hand, and their industrial environment on the other. Thus, the first step is to locate such activity and then find ways to bring these scientists and engineers together into local and international professional societies and integrate them into national and regional industrial activity.

Scientific activity is organized within the framework of so-called "invisible colleges", which are built around research-active scientists and their system of communication and exchange of information. Hence, the importance of research-active scientists.

Once accurate information on research activity is routinely available, the next step would be to promote networking and cooperation among these different parties. A number of standard mechanisms for networking and inducing cooperation between universities, industry and R&D centres are available.

Coordination must be achieved within professional societies and through direct contacts between professionals employed in industry and universities.

Recommendation 2: expansion of the scale of R&D in MSE

A great deal of emphasis should be placed on the expansion of the scale of R&D, the improvement of its quality, and the promotion of cooperation between the different parties producing materials.

The research output of the Arab countries published in international periodicals is doubling every seven years. Thus, the Arab countries already possess a large and significant pool of professional manpower active in most, if not all, areas of MSE, and it is growing at a good rate. Needless to say, all of this growth and activity is taking place without serious or determined effort to establish a significant capability in MSE.

What is urgently needed is to speed up the process of expansion of R&D in MSE in the Arab countries. To do so, a substantial increase in funding is required.

Recommendation 3: promotion of multidisciplinarity and reduction of bureaucracy

The development of MSE has been heavily coloured by the synergetic relationships between the different fields of science and engineering. New instrumentation, new chemicals, new processes, new demands, new methods to calculate the properties of physical systems have all made significant contributions to MSE.

Thus, one of the most striking features of MSE is that it involves almost all the sciences (chemistry, physics, engineering, mathematics, computer science) at the same time. It is not possible to make any significant advance unless the vision of scientists and engineers has been trained to be capable of encompassing a wide range of inputs. Multidisciplinarity is one of the most visible and important aspects of MSE.

In many Arab universities, a professor can only teach a course that he has taken as a student; moreover, it is impossible to appoint a person who holds a degree in physical chemistry to a department of physics, and so on. This bureaucratic approach to scientific activity makes the development of multidisciplinary departments impossible. Every effort should be made to break down the walls that now prevail in Arab universities between scientific disciplines. The control of planning by bureaucrats, in isolation from innovators and scientist, is not only meaningless but counter-productive. There is no substitute for the participation of active research scientists and engineers in all serious planning. Innovators, inventors, scientists and manufacturers must be the effective leaders of an MSE industry if that industry is to be successful.

Recommendation 4: promotion of contracting R&D services to national institutions

As may be surmised from the papers presented at the workshop, OECD countries are devoting considerable resources to promoting multidisciplinarity through the improvement of industry/university cooperation in R&D and training. The EEC has adopted several complementary R&D programmes with a view to intensifying the level of cooperation between firms and universities. The obvious reasons for this strong commitment to cooperation between various types of institutions and manufacturing firms are rooted in the inter-disciplinarity of materials technology. Industry/university research centres have been created in the United States with emphasis on fibre optics, ceramics, composites and so on.

Coordination and cooperation may be strongly enhanced through a system of R&D contracts sponsored by industrial firms and supported by government assistance. A number of Arab countries have already adopted measures to promote cooperation; what is needed is a more determined and larger-scale effort in the MSE field.

The industrial base of Arab countries is technology-depleted. In order to overcome this depletion, the starting point must be the re-integration of the industrial base with the missing technology. Two measures need to be adopted by industrial firms: first, scientific manpower must be absorbed in order for the firms to fully integrate technologically; secondly, the firms must utilize the services of national CEDOs (Consultancy Engineering Design Organizations) and R&D centres and universities.

Recommendation 5: adoption of procedures for the selection of priority areas

It is possible to develop a national or regional MSE programme based on its known features, but such a programme would be arbitrary and bureaucratic. In order to be useful, the programme must be solidly based in Arab scientific institutions and should respond to industrial demand.

Once a sound programme is established, it will pursue its own logic and respond effectively to international challenges and innovations. Scientists, engineers, and industrialists who are active in a field can evolve new and effective strategies to expand their activities in new directions. Bureaucrats without hands-on experience in the field cannot do the same; experience shows that they usually opt for sustaining their control rather than launching a successful industry.

The demand side has already been examined, and the existence of a large number of potential prime movers has been shown. It is essential that a systematic effort be made on the national and regional levels to identify firms which are serious about developing and establishing industrial activity in materials. Their demand should set the priorities for applied R&D programmes.

Naturally, universities should also be supported to develop basic research in materials science. Given the limited financial resources available, it would be impractical for each institution to initiate work in more than a few MSE areas. It will be necessary to develop some cooperative programmes between the various institutions to cover all the priority areas.

Effective methods to integrate R&D activity with investment programmes and procurement requirements are urgently needed.

Recommendation 6: development of manpower requirements for a regional MSE programme

The proper assessment of manpower needs will necessarily be based on demand by industrial, academic and R&D programmes. In the absence of such data, a rough number for the purpose of the present report can be estimated on the basis of the experience of industrial countries.

A 1986 survey by the (United States) National Science Foundation found that United States materials industries employed 21,800 out of 72,600 physicists; 61,800 out of 187,700 chemists; and 53,000 materials engineers. Thus, the core population employed in the materials industry totalled 136,000 individuals. This manpower was employed as follows:

(a) 40% in R&D;

(b) 18% of physicists and chemists and 3% of engineers were employed in teaching;

(c) 2% of physicists, 18% of chemists and engineers were employed in production;

(d) The balance was employed in other activities.[8]

Since the 1970s, United States universities have been graduating some 1,000 B.S. engineers in materials science annually. The number of Ph.D.s graduated annually with a specialization in materials is about 700. This rate has also been nearly constant since 1970.

There are approximately 100 United States university departments that offer B.S. programmes in materials sciences and engineering. Only 80% of these departments have the word "materials" in their name; in 1970, only 50% had the word "materials" in their name.

These departments are staffed by about 1,000 professors, 70% of whom had specialized in metallurgy. This shows that the origins of the materials industry in the United States are in metallurgy. Of the remainder, 12% specialized in ceramics, 9% in polymers, 9% in semiconductors, magnetic and optical materials. Some materials science departments grew out of physics and chemistry departments.

The United States also has the benefit of very extensive programmes in continuing education. These programmes enable professionals to move from field to field and to respond rapidly to changes in market demand. United States analysts estimate that there is pressure to increase the rate of production of professionals and to improve the available training courses and textbooks, with emphasis on synthesis and processing. There is also a call for the expansion of continuing education.

From the figures presented above on the United States, it is clear that the number of professionals required to develop a materials industry is not enormous. Therefore, among the

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[8] *Materials Science and Engineering for the 1990s: Maintaining Competitiveness in the Age of Materials*, Committee on Materials Science and Engineering, National Academy Press (Washington, D.C., 1989).

600,000 to 800,000 Arab engineers and the 20,000 Arab Ph.D. physicists and chemists, one should expect to find a substantial number of materials scientists and engineers. Many of them could, if they so wished, retrain and pursue careers in materials science. Thus, attracting 1,000 to 5,000 scientists and engineers should pose no serious difficulty.

There should be no self-imposed constraint toward non-Arab professionals: every attempt should be made to attract first-rate scientists and engineers, irrespective of their nationality. Only first-rate scientists can establish relevant programmes and educate a generation of competent Arab scientists and engineers.

Once a small core population of expertise has been put in place and given the appropriate support, the next priority should be to encourage a small number of engineering schools and university physics and chemistry departments to offer B.S. and Ph.D. degrees in material sciences. The goal should be to establish some 10 to 20 such departments with a view to graduating some 50 Ph.D.s and 200 B.S.s per year.

The absorption of 50 research scientists per year will require substantial investments (about $1 million per scientist per year) in equipment and facilities.[9] It may be necessary to pursue post-graduate education in industrial countries, and in all cases researchers should receive extensive post-doctoral experience in first-rate institutions. Only those exhibiting high levels of creativity should be recruited for university posts in the Arab countries.

During the first stage of such an MSE programme, most of the research professionals will be expected to be employed by materials science university departments. With time, it may become necessary to increase the number of graduates, depending on market demand.

A significant number of technicians will be required in order to operate large numbers of sophisticated testing equipment, manufacturing facilities and ancillary services. These technicians may be trained at specialized technical schools to be equipped for such a purpose.

Recommendation 7: expansion of R&D programmes

The development of a sensible programme in materials science and engineering must be based on a multi-pronged approach with emphasis on traditional materials (cement, bricks, traditional ceramics, leather, paper), materials now produced in the Arab countries (such as iron, steel, aluminium, plastics) and, finally, advanced materials (silicon, superconductors, carbon fibre, composites, engineering ceramics) not currently produced in the Arab countries.

A concrete and effective strategy would be to improve traditional materials in common use. The R&D to support such an activity may best be located in the industrial firms themselves so that they will be better aware of the opportunities. Such an approach would generate immediate economic returns and improvements in the quality of construction materials, fibres and textiles and leather. Such a strategy, if diligently pursued, would contribute to confidence-building and the promotion of the establishment of infrastructures and MSE policies.

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[9] It is necessary to bear in mind that the cost of laboratory facilities has increased considerably over the past 20 years; new facilities are more complex and more expensive than those used previously.

Arab metallurgical industries are relatively young and suffer from both the poor quality and high cost of their products; much attention should therefore be given to the transfer of technologies related to these industries.

Finally, careful attention should be given to the development of small, high-powered, programmes in many areas of materials science and engineering where applications in the Arab countries may still appear remote.

The planning and establishment of research teams and MSE industries must take place according to objective and design rather than bureaucracy.

Recommendation 8: development of requisite information services

Serious activity in science and technology requires an efficient system of information. Science is based on the principle that it is wasteful to rediscover the wheel. Unless a scientist has access to information on the more than one million materials that are currently produced, he would be wasting his time either by rediscovering already known materials or by studying their already known properties.

Scientific research is concerned with adding something new to knowledge; technology is concerned with utilizing known facts to manufacture a better quality product at a lower cost. All these activities call for the massive generation, dissemination and use of information.

Scientific work today is no longer performed by an isolated scientist. R&D and applications of scientific knowledge are in constant need of inputs of highly specialized professional services in information.

Of course, the above remarks apply to all the sciences and engineering disciplines. However, the multidisciplinary nature of MSE is so intense that, without adequate information services, workers would be totally paralysed.

Recommendation 9: improvement and application of high standards and quality control

In the Arab countries, the application of high standards has often been neglected. The improvement of the production of old materials as well as the introduction of new processing technologies call for the rigorous application of high industrial standards. This, in turn, calls for advanced instrumentation and highly skilled technical staff.

The problem is twofold: first, there is the need to develop an industrial culture that supports rigorous testing, application of standards and quality control; secondly, there is the need to train technicians to rigorously apply standards. Such challenges can only be met through massive efforts in technical education.

F. *The role of national, regional and international institutions*

It is clear from the analysis presented in the preceding chapter that individual Arab Governments and national institutions should undertake most of the effort required to develop MSE. This is because Government is responsible for higher education, R&D funds, a high proportion of industrial investments, tax laws and financial regulations.

Furthermore, the largest firms in the Arab countries are parastatals, and the policies of these parastatals could have a tremendous impact on the behaviour of the private sector: if these parastatal firms adopt policies that encourage small firms to develop capabilities in small-scale, hi-tech MSE industries, they could assume an important role in encouraging the development of local industries.

There are numerous regional associations of industrial firms in the Arab countries. Such associations could assume an important role by adopting positive policies towards the promotion of inter-Arab cooperation and the inter-Arab flow of MSE information.

The recommendations presented below aim at a series of measures that may be undertaken readily and at low cost. The establishment of the recommended networks, services and institutions should result in a sound and efficient infrastructure on which to build a more ambitious programme. Without such an infrastructure, it is unlikely that the region could build a sound and durable MSE industry.

1. Role of Arab Governments and national organizations

The promotion of MSE in the Arab countries calls for the following type of actions:

(a) The promotion of communication between scientists and their integration into national, regional and international networks. This recommendation applies to countries which already sponsor R&D in MSE. It entails financing national professional meetings and travel by scientists to attend two or more professional meetings per year outside their country. The cost of this activity is modest;

(b) The identification of current MSE activity. This recommendation involves the financing of directories of research in progress;

(c) The support of universities and technical institutions to develop new facilities and R&D programmes;

(d) The promotion of cooperation between universities, R&D centres and industry. This recommendation involves the financing of cooperation programmes. The basic idea is to assist industrialists to negotiate research contracts with competent researchers to resolve specific technical problems;

(e) The identification of national MSE priorities and the systematic adoption of relevant policies to acquire technological capabilities in these priority areas. This recommendation involves the mobilization of scientific manpower, industrial firms and importers of advanced materials to discuss national priorities. The focus should be on a few areas where the country (and/or region) could, in a reasonable time, acquire useful expertise in testing, R&D, manufacturing and/or R&D;

(f) The identification of demand-side prime movers and the allocation of the necessary resources to enable them to become direct players in the development of national MSE capabilities. Ad hoc measures should not be taken to establish research centres through turnkey contracts. National and regional consulting and contracting firms must be invited to participate in the preparation of studies and discussions so that they will be aware of the opportunities and will have the occasion to become familiar with MSE technologies.

2. Role of regional organizations

A number of regional organizations could assume an important role in the development of cooperative arrangements between the demand and supply sides for MSE expertise.

The regional organizations are:

(a) Those that form part of the League of Arab States system: IDCAS, Arab Labour Organization, ALECSO, AFESD, the Federation of the Arab Chambers of Commerce and Industry, the Standards Union and others;

(b) Subregional organizations such as OAPEC, the various industrial organizations that group fertilizer producers, iron and steel industries, cement producers, and so on;

(c) Associations of engineering and professional groups, the Arab Union of Contractors, the Arab Medical Association and others.

It is recommended that each of these organizations (and all those not mentioned above) promote those aspects of MSE that are of potential concern to its members.

It is further recommended that each regional organization should contribute to the effort at networking scientists, engineers, institutions and relevant government departments with each other and with relevant international organizations.

These activities are not expensive, but they are of vital importance to the formation of an adequate MSE infrastructure.

3. Role of ESCWA and international organizations

It is recommended that ESCWA collaborate with national institutions in order to establish a regional data-gathering system. The objective would be to publish on an annual basis up-to-date directories of research institutions, scientists and engineers, industries, publications, meetings and conferences on MSE.

It is also recommended that ESCWA (in collaboration with other United Nations agencies such as the United Nations University, UNESCO, UNIDO) sponsor workshops, summer school and university degree programmes in MSE areas having immediate importance. This sponsorship could be shared with Arab industrial consumers of MSE service.

REFERENCES

1. Committee on Materials Science and Engineering, *Materials Science and Engineering for the 1990s; Maintaining Competitiveness in the Age of Materials*, National Academy Press, Washington, D.C., 1989.

2. Lakis Kaounides, "Final Report of the Expert Group Meeting on Materials Policy Issues", UNIDO National Materials Policy Project, TIFAC/Department of Science and Technology, Bangalore, India, 11-13 December 1991, UNIDO, July 1992.

3. *A Strategy for the Development of Science and Technology in the Arab Nation; The General Report and the Sectoral Strategies*, the ALECSO Committee for the Development of a Strategy for Science and Technology in the Arab Nation consisted of: Abdallah Wassek Chahid (Chairman), Elsharif Hajj Sleiman, Abd el-Wahab Bouhdeba, Mahamad Razzouk Kaddoura, Ahmad Abed el-Rahman El-Aqeb, Antoine Zahlan, Adnan Badran, Mohamad Othman Khadr, Ossama el-Kholy, Saleh el-Athel, Issam Naquib and Musa Muhamad Amr; published by the Centre for Arab Unity Studies, p. 642, Beirut, 1989. In Arabic; also available in English.

4. A.B. Zahlan, *Acquiring Technological Capacity: A Study of Arab Consulting and Contracting Firms*, Macmillan, London, 1991. (Also published in Arabic by the Centre for Arab Unity Studies, Beirut, 1991.)

Discussion of Part Four, Paper One

Mr. Suham Al-Madfai:

Q. The figures here are taken from scientific capabilities, literature, magazines and publications, but I believe that to use the term Arab is misleading. These figures do not indicate the scientific capabilities of Arabs but their scientific efforts. Much has been done in the Arab world; there is, however, the problem of not reporting it and the problem of scarcity of science managers and of scientific institutions, people who can really manage research centres. These centres need more than just normal management; they need special managerial talents. This is to be emphasized. I would also like to say that strict reliance on publications figures would be misleading. Often universities in the region fail to provide full information on their publications.

Mr. Mohammad Jarrah:

Q. I would like to comment on the difficulties we face in Arab universities. In general, and this is a common third world problem, when you finish your graduate studies and come back to work in your country, you end up in academic work, that is, teaching students. Often you will have a heavy load of teaching for at least four different courses per semester, leaving you with very little time to do practical research or basic research. Moreover, as the society is not technologically advanced, nobody attempts to solve practical problems or industrial problems. In addition, for your promotion you look for different types of publications. For example, in our case, five publications in recognized journals are needed before you can be promoted to assistant professor. You go to the library and look in the magazines to find areas you can work in. Thus, to find a problem to work on in a third world country is a major issue. You spend three or four months looking in different journals to find an interesting topic to work on. In the United States or Europe, people approach you with problems and you work on them. Another problem is that we do not have a graduate programme in the region. The graduate programmes we have are very weak. They do not relate to industry. They are predominantly research in academic problems for students preparing for their Master's degrees. The problems researched are not necessarily relevant to the development of the region. These are my comments about why, when you relate publications to the number of people or researchers, you find them low and of limited value compared with those in other regions.

Mr. Ghazi Derwish:

Q. I must first go back to table one. Although it was referred to by previous speakers, I would have thought the numbers, or rather the statistics quoted, could be more informative if we were told not only about the scientists who put their names on the publications, but whether or not the actual research published was carried out in the national institute or in the place where the sabbatical periods were spent. As a general practice, most Arab scientists tend to mention their national institute in the papers rather than the names of the actual places where the research was conducted. I think this has to be carefully looked into before we make any deep analysis of the figures quoted in table one.

Another indicator would be the number of national patents registered in the country. In relating this to the research publications, one could get an idea as to the relevance of the research done to the need of that particular country. This is because, in most cases, if the research is of relevance to the country, especially to industry, it would end up in a patent preceded by a publication. So, in my view, another indicator of interest would be the number of patents published or registered or granted to the nationals of a country by the agency responsible for patents or industrial property in the country. I would also like to take a point with Mr. Zahlan where he mentions in the introduction to his paper that the great advancement in materials science is going to be in quantum physics, etc. He completely neglects the great role played by chemistry in the field of materials science.

Mr. R.S. Ganapathy:

Q. I have only two questions and one comment for Mr. Zahlan.

Something which puzzled me was that, while the data showed an enormous resource base in the region in terms of qualified people, researchers, etc., the impact on industry and productive activities seems to have been minimal, so I have two questions: first, what could be the reason for not utilizing these resources productively? Is it because (and this is what happened in India) the tradition of decision-making based on scientific knowledge is poor?

Second, there is obviously a big gap, and the parallel with India exists here too, between generating knowledge and utilizing knowledge. There is a very big gap and there are many institutional, cultural and other factors behind it. We conducted a survey in India as part of our project to look at the nature of materials research in the last 10 years. The analysis was similar to yours. We looked at publications and citation data in both Indian and international publications, which amounts to about 6,000 publications. There are about 12,000 publications on select subjects, not always relating to materials; so in all 12,000 publications/articles were analyzed. We found that one possible reason for this gap is that 80% of the publications were actually on structure-property relationships and material characterization. This is obviously a very secure way to distribute research priorities. If so much research is in limited characterization and structure property relationships, this is because they do not take much research and they are probably repetitive and it is advantageous to do that kind of research to get a Ph.D. or a Master's degree. Obviously, this research will have a very poor impact on the production system if you want to bring cost reduction, product innovation or process improvement, this research is not good, you are here to go beyond that, only 1% of the research was on applications and 3% on manufacturing and synthesis and process issues. So, I do not know whether the situation in the Arab world in the data which you have shown has a similar trend.

Finally, and based on this, you know that until about the nineteenth century the worlds of materials and materials-based industries were essentially technology driven. There was initially the technology in practice, and the knowledge came later, science came later. But now we have a situation, as it is clear in Mr. Kaounides' paper, that the advanced materials industry is particularly a science-driven one. Knowledge is there first and then technology. This is actually a big paradigmatic shift in the nature of the materials industry. I do not know whether given that fact the advanced materials are essentially based on science rather than technology and practice-driven. What would you think are the priorities? You mentioned this as one of the action points. I would like you to speculate on the priorities for the Arab region, in view of its resource base and the existing structure and the way knowledge is generated and utilized.

Mr. Ali Dajani:

Q. I was listening carefully to the presentations this morning, and I very much appreciate what has been presented to us. I direct my comments to first to Mr. Kaounides; I think he has done well to inform us about an aspect which he did not mention directly and this is the commercialization of science and technology. He is right and we should learn this lesson. I come to Mr. Zahlan's presentation; Mr. Zahlan is a well known personality in the Arab world and I think he participated in the seminars on science on some occasions in Jordan if I am not mistaken. Of course, when Mr. Zahlan made his presentation, it came to be a bit too general in my mind, and I wish he had selected some sectors of the industry or of science where we should concentrate. We cannot go as Japan or the United States or the United Kingdom are going; we have limitations in the Arab world because of the natural resources that we have, and secondly I think Mr. Zahlan has not visited the area as a whole for some time. I think we were the first in Jordan to organize a conference during the 1980s to lay down a national policy for science and technology. This year, two months ago, we hosted Arab scientists of American citizenship in Jordan, and they discussed ways and means of transfer of technology to Jordan. I would therefore like to tell Mr. Zahlan that our leadership may be bureaucratic, but I do not think it is rigid regarding science and technology; otherwise we would not have seen, in a country as small as Jordan, 10 universities active in many aspects of science and technology. As far as the private sector is concerned, we are contributing from the net profits of companies 2% for universities and 1% for science and technology and training. The basic point is that we have to look at things at the base. I think training young men at work and providing advance training to enable them to absorb the technicalities of the work, especially in industry, is essential.

The other point that we have to look into is that in the Arab countries we must select a subsector or a sector and look into it thoroughly to see what we can do. I think we can address ourselves to several interrelated sectors. For example, the medical sector is a highly successful sector in the Middle East. Jordan, for example was the first to perform a heart transplant operation, as is well known. Secondly, I think they are doing very well in engineering and in industry. Industry in Jordan has now gone into electronics and pharmaceuticals with much success. I would like, therefore, to ask Mr. Zahlan to help us to concentrate and, with the help of ESCWA, to select one or two sectors of science and technology for real consideration.

Mr. Ferhanq Jalal:

Q. I agree with what was mentioned about the important role of the state in our countries in the field of materials technology but I would like to emphasize one aspect of the role of Government and that is how our Governments can facilitate cooperation between the science and technology community both from the supply and the demand side as in the science and technology community in other countries especially the advanced ones. I also emphasize the importance of cooperation between developing countries, but I think cooperation between our countries and the advanced countries is even more important. My second point is that United Nations organizations such as UNIDO and ESCWA have a very important role to play in facilitating this cooperation between advanced countries and between the developing countries, and I hope that they will continue to do so in the future.

Mr. Antoine Zahlan:

Ans. First, regarding the Kuwaiti publications, the list of publications is for institutions and not by the nationality of the people in that institution.

In answer to Mr. Al-Madfai, the problem of whether a university accepts 10,000 students or one is irrelevant to the table he referred to.

Regarding table one, in my paper you will find further explanations. Two series of all publications in the Arab world are in medicine and agriculture; the medical ones are mostly from hospitals, medical schools and universities, and they are all local. They are applied to the problems of the area; only one third is about all the remaining subjects. Some (around 5%) may have been done abroad. In 1966, in the Arab countries, there were nearly 34 universities; now there are 86, and there is much more going on locally these days.

R&D is very much concentrated in biology, medicine and agriculture. It is mostly oriented towards the science and not so strong on the applications. Practically 99% of industrial projects of substance are done by foreign consultants with little local involvement. There may be an Arab scientist in the ministry or the company who goes to talk to the consulting company abroad, but there is very rarely any effort to unpackage the technology. This is one of the reasons why our resources have not been integrated effectively. Of course, I was a little general in my presentation, but I was also very specific because scientific activity has certain ingredients which you have to have, such as electricity and water and so on. Regarding the list, I have a few items which are very strictly related to materials science and technology engineering, but mostly I agree that they have to do with the way we interact with science and technology, and it is not very often the fault of Governments, although sometimes I think it is a cultural problem. According to our survey, in 1986, the Arab countries devoted 0.2% of their GDP to R&D. According to UNESCO—I have it also in the paper—it is about 0.8, 0.9, 1% of the GDP on R&D both figures are still very small. If you want to do this kind of planning, it would take too much time, the Governments take too much time with an idea and this is a fast-moving subject. I mean you cannot take ten years or three years to decide on something unless you integrate industry and university and so on; you cannot do very much if they are not integrated. We wish they were and, as indicated in my papers, some are trying, albeit with very limited success. So all of this is very strictly related to materials science and engineering. In a way, the discussion is general. Because we are not talking about how to make composite fibreglass materials but about what the implications are for us, and these are some of the implications.

PART FIVE

I. RECOMMENDATIONS

A. *Workshop recommendations*

Recommendations to deal with existing obstacles and constraints

This part of the recommendations is directed towards the obstacles and constraints that are currently impeding full utilization of the existing opportunities.

1. New MSE curricula and human resource training are needed to meet the multidisciplinary requirements of materials science, processing and application. (All this emphasizes the central importance of education policy).

2. Materials synthesis and processing capabilities are needed in both conventional materials and new and advanced materials.

3. Standard measurement, testing, and evaluation methods are required in order to facilitate the improvement, acceptance and diffusion of improved conventional, new, and advanced materials.

4. Responsible practices are needed to take into account the effect on the environment of effluent derived from all processes in the materials chain and to take steps to monitor and manage pollution control on existing and traditional processes in accordance with international standards. Furthermore, new "clean technologies" which result in minimum effluent at each stage should be encouraged. The responsible development of materials in the context of the "cradle to grave" approach implies a policy on the environment without which products from developing countries may not find markets in the developed world.

5. The institutional and legal framework for technology transfer, licensing, joint ventures and protection of intellectual property rights needs to be strengthened.

6. Manufacturing, engineering, R&D and design engineering skills as well as the need to integrate such skills effectively are important.

7. Close collaboration and cooperation are needed between materials producers and users in simultaneous materials, product, and manufacturing design.

8. Multidisciplinary multi-materials R&D institutes are needed to assist public and private industry in human resource training, technology transfer and innovation. Existing ones should be strengthened.

9. Close institutional links are needed between materials R&D in Government, universities and industry and its effective transmission into production and commercial use.

10. There is an increasing need to enhance awareness and greatly improve the dissemination of information on developments in the materials field and their likely consequences.

11. A high-level advisory body is needed at the national level. This multidisciplinary materials science and technology body would assist the economies in offering appropriate responses specific to each country for dealing with the threats and opportunities created by the advances in materials technologies. Its functions would include science and technology analysis, forecasting, and formulation and implementation of national materials policy.

12. *Regarding regional responses to the materials revolution*, the recommendation emphasized:

(a) Regional collaboration in pre-standards research and development of common standards in measurement, characterization, and testing methods.

(b) The need to focus on the areas identified below. These can be resolved through collaboration in the form of regional materials research, processing and applications centres and/or the regional networking of existing research institutes and centres of excellence:

(i) Assisting the region to address the issues raised by advances in materials science and engineering and develop scientific and engineering capacities;

(ii) Assisting in the upgrading and utilization of local materials for regional use to meet basic needs;

(iii) Assisting private industry to increase its materials R&D, processing and application skill;

(iv) Fostering the formation of links and cooperation between countries in the region through the exchange of information, experience, joint R&D programmes (e.g., in ceramics, glass, fine chemicals, etc.), and human resource training;

(v) Collecting and disseminating information of scientific, engineering, techno-economic and industrial relevance in the fields of materials science and engineering;

(vi) Carrying out joint R&D design, synthesis and processing, fabrication, testing, measurements and evaluation of new materials. Addressing the need for pre-standards research, common standards and quality control;

(vii) Conducting joint R&D programmes with private industries (pre-competitive and/or near market);

(viii) Providing managerial, financial and technical advice to new business ventures.

B. *Recommendations for Governments*

The following recommendations are advanced specifically for the consideration of Governments.

Recommendation 1: ***Creation of national MSE bodies***

Materials-based industries are multidisciplinary in nature. As such they require the involvement of all ministries and major industrial organizations and research centres involved in the design, production and use of materials. Each country has its own special conditions and needs and is best equipped to bring together its own expertise to address the challenges and opportunities. This does not negate the importance of regional and international cooperation.

It is thus recommended that the Governments of the ESCWA member States institutionalize policy-making and planning in order to integrate national efforts in this field. It is also recommended that a national body be established to address this challenge. This body should include representatives from governmental bodies, educational institutions, unions of engineers and scientists, universities and concerned associations, as well as experts in MSE from the major industrial firms, R&D institutions, and international trade and finance sectors. The focus of the expertise should be on materials science and engineering.

Recommendation 2: ***Dissemination of information***

The expert meeting noted that over the past 30 years the Arab countries have developed some industrial and professional expertise in MSE which includes a large number of industries, manpower and R&D facilities. However, many of these resources are not sufficiently well-known nationally or regionally. It is believed that the full and optimal utilization of these capabilities can be realized with modest additional expenditure of effort and resources; such measures should contribute significantly to the expansion of the national and regional economies.

It is thus recommended that the Governments of the region and ESCWA cooperate to:

(a) Locate, identify and define materials-based activities;

(b) Prepare, publish and disseminate accurate information on industrial and manpower capabilities on an annual basis;

(c) Promote the diffusion of information and communication between experts in MSE and identify the market demand to enable proper planning.

Recommendation 3: ***MSE research and development***

The workshop emphasized that the rate of progress of materials technologies is extremely high. This means that R&D is necessary not only for developing new technologies but also for selecting the most appropriate ones to adopt. It is believed that a competent R&D programme in MSE is of central importance.

It is recommended that the Governments of the ESCWA region and regional organizations support, upgrade and strengthen existing R&D programmes before creating new ones. There already exists a number of R&D programmes which could be strengthened and expanded. It is of prime importance to first develop existing programmes to an international level of quality and scope.

Recommendation 4: ***Trade in materials***

The market for new and advanced materials is international. It is recommended that attention be given to reducing regional and international barriers to trade in new and advanced materials. Also, attention should be given to the elimination or reduction of barriers to the transfer of technology.

Recommendation 5: ***Articulation of all key parties into the process of planning***

The workshop emphasized the multidisciplinary nature of MSE. The development of an internationally competitive industry depends on the articulation of industry, designers, engineers, R&D scientists, economists and educators in all the key operations of this industry.

It is thus recommended that Governments evolve the process of planning and development to fully involve industrialists, scientists and engineers in an effective and direct manner.

Recommendation 6: ***International cooperation in educational planning***

Material science and technology is being pursued all over the world, and naturally there is considerable benefit to the member countries in strengthening their technical cooperation with other regions in educational planning and policy planning.

It is recommended that the Governments of the ESCWA region benefit from international efforts by various means: attending meetings, participating in international studies and international research programmes in these domains.

Recommendation 7: ***Financial services and incentives***

Financial incentives are powerful instruments for the promotion of a materials industry. It is recommended that the Governments of the ESCWA region adopt suitable incentives to encourage R&D and production of advanced materials. The measures may be in the form of subsidies, tax exemptions, export-promotion incentives, new regulations to promote the establishment of venture capital markets and financial services that facilitate investment.

Recommendation 8: ***Development of university departments in MSE***

The workshop noted that the existing manpower of the countries of the region, including expatriates and those who are temporarily abroad, may be adequate for any immediate effort in this direction. Short training courses are needed to retrain existing professional manpower for specific occupations.

However, any successful programme for the establishment and development of industries in new and advanced materials will eventually require specialized MSE professional and research manpower. It will not be possible in the near future for any country in the region to develop university programmes to cover all the key areas of MSE.

It is thus recommended that:

(a) The universities of the region cooperate among themselves to develop specialized departments in the different areas of MSE;

(b) The different departments in these specializations should be established with adequate facilities and expertise;

(c) The new departments develop suitable curricula in cooperation with international effort;

(d) The various universities cooperate with each other in the sharing of expertise and R&D programmes and in the exchange of students at both the undergraduate and graduate levels.

Recommendation 9: ***Standards, testing and quality control***

The workshop emphasized that the adoption of high standards and quality control in design and production is essential to the production of advanced materials. The regional and international marketing of these products also depends on the adoption of such recognized standards as well as the availability and dissemination of information on these products.

It is thus recommended that Governments of the ESCWA region give considerable attention to the adoption and development of international standards, testing and evaluations and also support the acquisition and adoption of quality control measures throughout this industry.

Recommendation 10: ***National effort and regional cooperation***

The workshop emphasized that though each country has to adopt and implement specific national measures to promote the development of the materials industry, regional and international cooperation remains an important dimension.

It recommended that each country strengthen its capacity to cooperate with its regional partners and also benefit from full participation in international programmes.

This recommendation could be implemented through the establishment of scientific and technological Arab unions and organizations for the promotion and dissemination of information and enhancement of communication and cooperation.

Recommendation 11: ***Support by ESCWA and UNIDO to member States***

Finally, the workshop recommended that ESCWA, in cooperation with UNIDO, formulate a plan of action to assist those concerned in implementing those suggestions and recommendations which have a regional dimension and are of an urgent nature; and also to assist the member countries of ESCWA to meet some of the challenges in the areas of development, production, marketing and use of new and advanced materials.

II. LIST OF PAPERS PRESENTED TO THE WORKSHOP

1. Advanced Materials Technologies: Status and Development Trends
   Horst Czichos, Jurgen Lexow

2. Advanced Materials Technology and the World Economy
   Lakis C. Kaounides

3. Advances in Materials Sciences: Challenges and Implications for the Arab Countries
   A.B. Zahlan

4. Development and Advanced Composites
   Ian Marshall

5. Developing an Education Programme for New and Advanced Materials Technology
   John V. Wood

6. Processing for Properties Assessment and Predictability and Application for New Materials
   John V. Wood

7. The Horizontal System Approach for Integrated Materials Technology
   Wim F. Weppner

8. Testing and Evaluation of Advanced Materials
   M. Kamal Hossain

9. Development of Ceramics
   Malcolm McLaren

10. Development and Application of Advanced Materials for Solar Photovoltaics
    Mukkavalli R.L.N. Murthy

11. New Materials Technology and Sustainable Development
    Mammo Muchie

12. Materials Technology in India: Review and Prospects
    R.S. Ganapathy

13. New and Advanced Materials: the Nigeria Experience
    A.O. Aribisala

14. The Arab Petrochemical Industries and the Challenge of New & Advanced Materials
    Ghazi A.W. Derwish

15. Degradable Polymers and their Application in Agriculture
    Jabir Shanshoul

II. LIST OF PAPERS PRESENTED TO THE WORKSHOP *(continued)*

16. The Production and Development of Spheroidal Graphite Iron
Mohammed Hussein Al-Saden

17. Present Status of Materials Technology and the Future Role of New and Advanced Materials in Egypt
Mohammed Kamel Mahmoud

18. New & Advanced Materials Technology in Egypt
Yusef K. Mazhar

19. National Research Centre's Approach to New & Advanced Materials
N.M. Ghoneim, A.M. Attia, W.I.A. Fattah, and N.A. Saleh

20. Innovative Potential of Bioactive Bioceramics
Wafa I. Abdel-Fattah and W.G. Osiris

21. A Case History of the Use of Sheet Moulding Compound in Egypt in a Highly Dimensional, Minimum Contract Time & Severely Stressed Application
R.I. Bassyouni

22. Feasibility of Sheet Moulding Compound Material after its Expiration Date
Ahmed El-Sayed Atty

23. Applications of Fibreglass
Ibrahim A.M. Al-Mihy

24. New Materials and Technologies in Jordan
Falak H. Sarraf

25. New and Advanced Materials
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50. Mr. Ferhanq Jalal
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IV. LIST OF NATIONAL AND INTERNATIONAL INSTITUTIONS

National institutions

1. National Research Centre, Egypt
2. Ministry of Industry & Minerals, Egypt
3. El-Nasr Glass Company, Egypt
4. Arab British Helicopters Company, Egypt
5. Arab Corporation for Industrialization, Egypt
6. Ministry of Industry & Trade, Jordan
7. Industrial Development Bank, Jordan
8. Amman Chamber of Commerce, Jordan
9. Royal Scientific Society, Jordan
10. University of Science & Technology, Jordan
11. College of Science & Technology, Palestine
12. Ministry of Industry & Minerals, Iraq
13. University of Technology, Iraq
14. Baghdad University, Iraq
15. Al-Rafidain Consulting Engineering, Iraq
16. Graduate Studies Centre, Yemen
17. Science & Technology Centre, Yemen
18. Ministry of Trade & Industry, Qatar
19. Scientific Studies & Research Centre, Syrian Arab Republic
20. Damascus Chamber of Industry, Syrian Arab Republic
21. State Planning Commission, Syrian Arab Republic
22. Ministry of Industry, Syrian Arab Republic

23. Atomic Energy Commission, Syrian Arab Republic

24. Higher Institute for Applied Science & Technology, Syrian Arab Republic

International Institutions

Germany

1. Federal Institute for Materials Research & Testing (BAM)

United Kingdom

2. Dept. of Mechanical & Manufacturing Engineering, University of Paisley

3. Dept. of Materials Engineering & Materials Design, University of Nottingham

4. School of Environmental Sciences & Mathematics, Middlesex University

5. Materials Metrology, National Physical Laboratory, Teddington, Middlesex

6. Business School, City University

United States

7. Dept. of Ceramics, Institute of Engineering, Rutgers University

OECD

8. Committee on Education in Advanced Materials

India

9. National Materials Policy Project, Technology Information, Forecasting & Assessment Council

10. Semicon Tech. Consultants in Bombay

Nigeria

11. Materials Research & Development Council, Federal Ministry of Science & Technology

UNIDO

12. Technology Development & Promotion Division; the Arab Area Programme & the New Technologies Unit