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THE REVOLUTION IN MATERIALS SCIENCE AND ENGINEERING:

Multidisciplinary and Transectoral Implications of the Emerging New Materials and Manufacturing Era

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CONTENTS

Page

1. INTRODUCTION AND SUMMARY: The new materials era and developing economies.

Primary commodity, industrialisation, trade and development strategies in the 1990's must be devised in a radically different and fast changing global scientific, technological and manufacturing environment to that to which we have been historically accustomed in the major part of the post-war period. In this paper[1], we first identify those forces that have ushered in a revolution in the scientific and engineering technology base of materials design, production and use. We then link this ongoing transformation of the materials producing sectors to the emerging manufacturing technologies, as the industrialised advanced economies (IAC's) proceed along a slow and uneven transition to new methods of industrial organisation and production. It should be clear that divorcing the analysis of the materials producing industries from a thorough-going investigation of the circumstances and evolving requirements of the materials-using manufacturing industries can only result in partial understanding and misleading policy conclusions.

Decisions appertaining to materials issues require an understanding both of the trends in materials science and engineering (MSE) and of the restructuring process of IAC's. Economic forces, new market circumstances and corporate strategies are leading to a substantial restructuring, redeployment and reorientation of basic materials producing industries. This implies a reordering of the importance of regions and economies engaged in the production of traditional raw and semi-processed commodities entering domestic industry and world trade. At the same time, new technological and manufacturing conditions are leading to greater vertical integration between materials producers and materials users in industry. Thus, the materials sector is not only emerging as a high-tech in itself and a crucial determinant of technical change in other high-and science-based industries, but it is also an inseparable and necessary component of the move of the economic system towards more flexible methods of production and consumption, where materials must meet increasingly stringent performance and quality criteria.

A large number of developing economies remain heavily dependent on traditional primary commodity production and trade as a component of GDP, and in terms of employment, government revenue and foreign exchange generation, the letter acquiring even greater importance in the 1980's given the rise in external indebtness and repayment obligations. In its attempts to grapple with the well-known difficulties in this area, national and international commodity policy is at a cross-roads, beginning to recognise the need to go beyond traditional modes of thinking and remedies.

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[1] This paper draws on a much larger study by the author, entitled: 'Advanced Materials, the Restructuring of Industry and The Third World: The revolution of materials science and engineering and its implications for the global division of labour.' Institute of Development Studies, University of Sussex, (Forthcoming, March 1990) pp 160. For a more comprehensive coverage of the subject matter and greater elaboration of the arguments the reader is referred to the study above and the following: 'Advanced Materials and Primary Commodities: A review of recent scientific and technological developments and their implications for industrial policy and strategy. Paper presented at the Expert Group Meeting on Prospects for Industrialisation Policies in Development Countries Taking into Account the Impact of Developments in the Field of New and High Technology, UNIDO, Vienna, Austria, 4-7 April 1989. A condensed version of this paper appears in 'New Technologies and Global Industrialisation' UNIDO, P.P.D 141, (Forthcoming, December 1989). See also, 'The Materials Revolution and

Developing economies are important participants in world trade in commodities and manufactures. It is clear that urgent measures are currently required in the areas of debt relief, lower cost and enhanced flows of external finance, tariff reform and market liberalisation together with other mechanisms to strengthen their position in commodity markets, such that the most severe difficulties can be eased, if not alleviated, and the most pressing needs met. Nevertheless, necessary as such measures might be in the short to medium run, developing economies must reassess the conditions to be met and under which it would be advisable for them to remain, exit or enter into a particular stage in commodity production, and indeed the wisdom of a resource based industrialisation strategy. For, commodity issues are becoming deeply enmeshed in the new materials and manufacturing era and emerging best practice technologies. A corollary of this is that the new circumstances are not merely relevant to those economies engaged in the production of a specific primary commodity or monolithic material. Whether an economy remains or exits from a specific commodity, it still needs to be able to operate, compete and survive in a global market place characterised by a quantum leap in the knowledge-content of materials production and use and by the diffusion of microelectronics-based automation technologies and new forms of organisation of production across all manufacturing activities. As traditional sources of comparative advantage are being eroded, the conditions for foreign direct investment, plant location, global sourcing of materials and components, and the role and physical proximity of materials suppliers in manufacturing are all changing. This then raises important issues regarding the conditions which must be met in the 1990's in the areas of infrastructure, maintenance and support industries, skills and training, testing, standards and quality assurance, such that developing economies at different stages of socio-economic development can increase this participation in global industry, technology transfer and trade. These considerations will prove most critical in the case of the least developed economies whose commodity export and trade performance in the 1980's has led to unacceptable curtailments in domestic health and education expenditures, and an inability to maintain a deteriorating infrastructure and productive capacity.

It must be stressed that the materials revolution affords tremendous opportunities and potential gains of early entry for a great many developing economies. The new materials scientific and engineering base is not only capable of spawning clusters of new advanced metals, engineering polymers, advanced ceramics, and composite material systems, but can also lead to substantial improvements in the processing and properties of existing materials. In fact, the acquisition of advanced processing and engineering competence in both new and traditional materials will be a central aspect of development and industrialisation strategies in the 1990's.

The current revolution in MSE mandates a multi-disciplinary approach to materials issues. At the same time the new circumstances lead, inescapably, to a strong transmaterial and transectoral approach to analysing and confronting issues related to materials, in contradistinction to the mono-material and specialised analyses, that proved to be adequate until recently. Boundaries and barriers between materials are eroding both at the science and production end, and at the market or end-use end, where there is significant interpenetration of materials across uses, and several materials compete for the same application.

These multi-disciplinary and trans-material aspects are beginning to have an impact across the whole spectrum of organisation of industrial R&D laboratories, university departments, educational curricula, professional societies and testing and standards institutes. For example, previously specialised professional societies and associations, as in metals or polymers, are transforming themselves to (multi) materials societies, Clearly the acquisition of interdisciplinary competences is also becoming a necessity and must be reflected in the institutions and government organisation of the economy at large, in order to be able to comprehend, and address the complexities, elusive nature and transectoral implications of the new materials era. Accessing, assimilating, and utilising materials information and data, as well as monitoring relevant trends in materials science and technology, and translating them into a set of appropriate domestic industrial and educational policies, requires multidisciplinary institutional capabilities within government, probably embodies in a specialised unit, council or nucleus, along the Brazilian example.

The new materials era and its attendant science and technology base necessitates the regional and international cooperation between developing countries in the areas of information and data gathering and exchange, education and training, materials science and technology research programmes and experimentation and the development of common and uniform testing, measurement and performance evaluation standards, which also conform to those being developing in IAC's. There is also a need to go beyond the networking of existing institutions and centres of excellence, and to set up international centres which can assist developing economies in both frontier scientific and engineering research and in monitoring, information gathering and dissemination, the generation of materials properties data bases and in techno-economic studies which would provide the basis for domestic industrial and educational strategic planning. The speed of change, the enormous complexity and multidisciplinary, transectoral aspects of materials issues mean that all opportunities for technical, economic and industrial cooperation between developing countries be grasped, and that collective approaches may be necessary, including the setting up of appropriate regional and international centres of excellence.

The greater participation of developing countries in the world economy, the more efficient utilisation of world resources and the scientific and technological upgrading of these economies requires an appropriately enlarged role for IAC's industry and institutions in the framework of market liberalisation and international cooperation. Finally, and most importantly, all such aspects of resource and materials utilisation and management have become inseparable from considerations of environmental impact and sustainable patterns of development. Acceptable solutions in these areas require regional and international cooperation and agreement. It is therefore becoming increasingly clear that the vastly enhanced science and technology base of MSE and biotechnologies must increasingly be directed to meet the needs of development while minimising pressure on the environment, energy and natural resources.

2 THE ORIGINS, CHARACTERISTICS AND CONSEQUENCES OF THE MATERIALS REVOLUTION.

2.1 The origins and characteristics of the revolution in materials science and engineering.

2.1.1 The nature of the radical transition of MSE.

During the 1980's it has become clear that this field of materials design, production and use is in the process of being radically and irreversibly transformed. At the root of this ongoing internal transformation, which contains the seeds for widespread ramifications throughout industry and the economy, lies the revolution in Materials Science and Engineering (MSE). A number of factors arising in concert are responsible for this.

The revolutionary advance in physics during the period 1895 - 1930's, greatly expanded our ability for scientific study and understanding of the structure solids, both crystalline and amorphous, and of the connections between the structure and properties of matter. Nevertheless, such deep and, continuously improving, insights offered by quantum physics, permeating as they did all physical sciences, could only be taken full advantage of relatively recently.

Improved understanding of the structure and composition of matter, and their relation to properties has meant an increasing ability to analyse, model, predict and control both the microstructure and associated properties of materials. Seen from the vantage point of the late 1980's materials science and applied research, is now in possession of such greatly enhanced analytical, theoretical, predictive and control capabilities with which to manipulate and build materials at the atomic, lattice, micro and macrostructure levels, that could not even have been imagined 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 and of time-dependent processes, starting with nothing more than the atomic numbers of the constituents".[2]

For centuries materials synthesis and processing relied on empiricism. In recent decades the analysis, synthesis and processing of materials has been benefiting from the incorporation of more fundamental scientific understanding, but these enhanced theoretical insights could only offer qualitative guidelines to modelling and prediction. In recent years, major new instruments (see Diagram 1), the availability of enhanced computing power able to handle vast amounts of generated data and to perform the trillions of calculations required for even the simplest of atomic arrangements, together with advances in process modelling, experimental and characterisation techniques and mathematics, have meant that materials scientists are now able to provide quantitative theoretical modelling guidelines in the design and processing path of materials. It is difficult to overstate the importance of such developments, which are beginning to provide a unified theoretical framework within which exceedingly complex problems relating to materials properties and performance in use, and the mechanisms by which they can be altered or degrade, can be addressed and new materials can be designed and developed.

Thus the scientific and engineering basis of materials today is such that not only is it possible to improve the processing and properties of existing materials but entirely new materials with predictable properties can be designed at the atomic or molecular level and processed so as to acquire the characteristics or combination of properties required in a specific application. It is this, almost miraculous, ability of material scientists to intervene at the atomic or higher levels, to analyse, predict and control the microstructure along the processing path, to manipulate properties and achieve performance characteristics necessary across an increasing number of technological, industrial and military applications that lies at the core of the materials revolution.

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[2] Materials Science and Engineering for the 1990's; Maintaining Competitiveness in the Age of Materials. Committee on Materials Science and Engineering, U.S. National Research Council, National Academy of Sciences, 1989, p 74. The arguments below owe much of this excellent and authoritative report.

DIAGRAM 1 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."

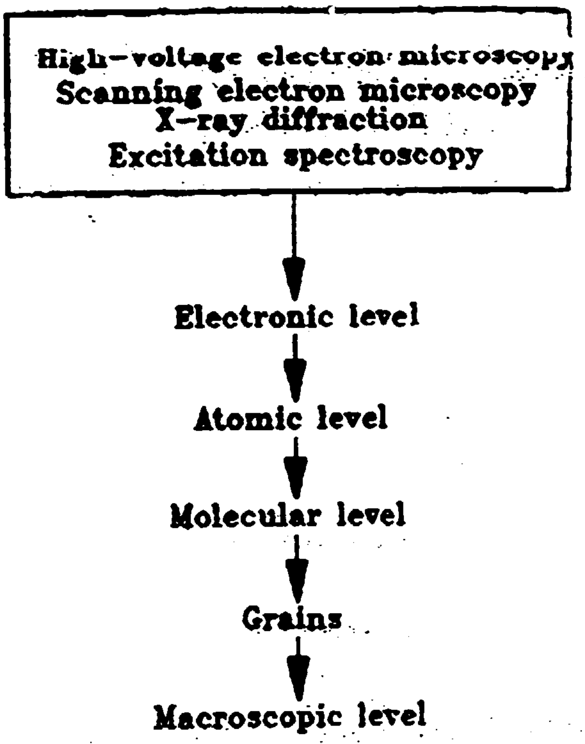
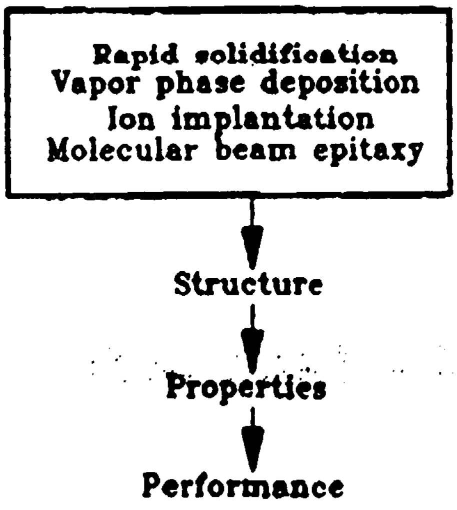


DIAGRAM 2 NEW MATERIALS PROCESSING TECHNOLOGIES

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

Such advances have enabled materials 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.

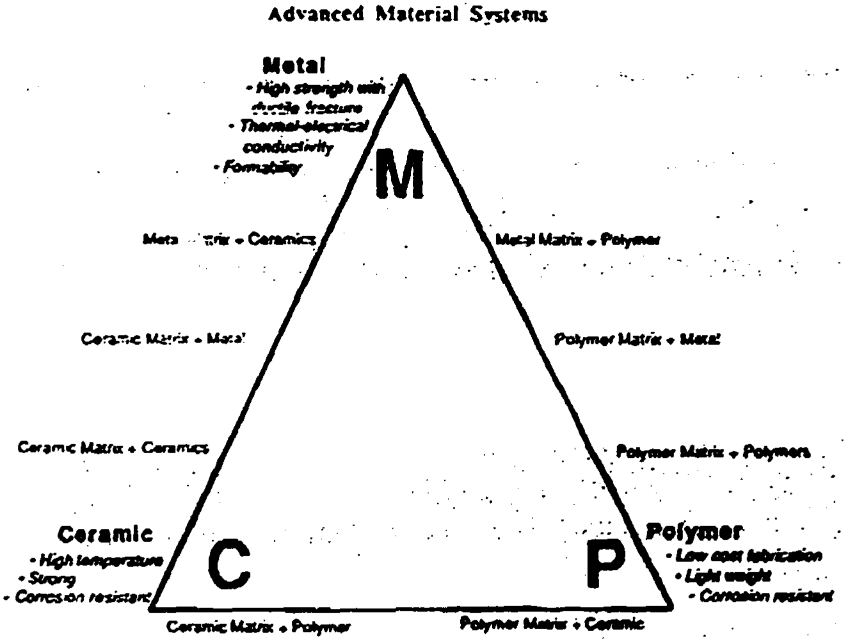


Source: L. Sousa, 'Problems and Opportunities in Metals and Materials', US Bureau of Mines, 1988

2.1.2 New advanced materials

A manifest consequence of these enhanced powers in recent years has been the proliferation of new interconnected clusters of knowledge-intensive high-performance materials such as advanced metals, advanced ceramics, engineering plastics and ceramic-,metal- and polymer-matrix composites, as shown in Figure 1 below, which are currently finding application in high-technology industries, where performance is more important than cost.

Figure 1.

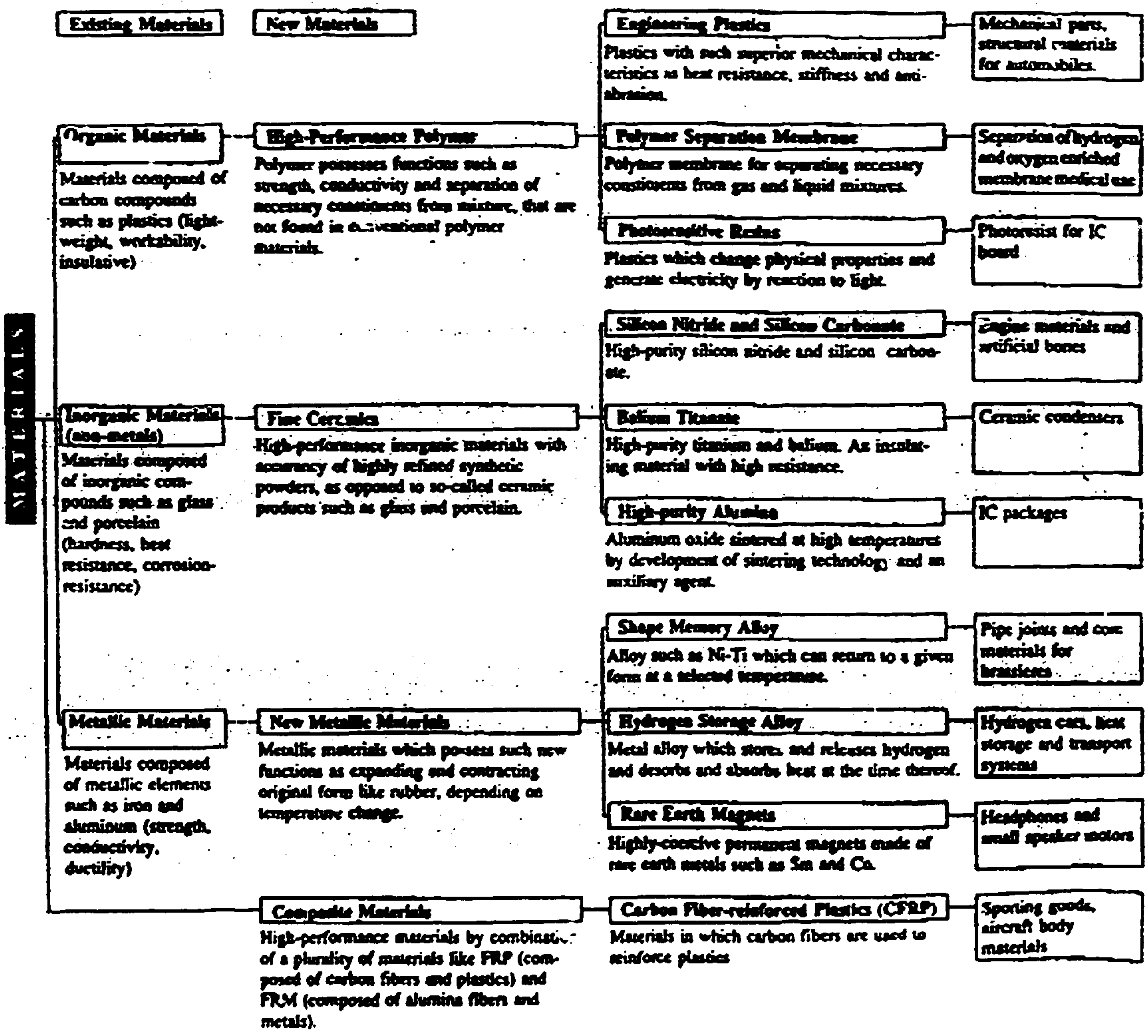


Source: Alcoa, Position Paper from the 10th Biennial Conference on National Materials Policy.

The arrival of advanced materials capabilities is leading to an acceleration in the rate of materials and product invention and innovation, more rapid obsolescence of products and processes, and a reduced life-cycle for new materials, which would necessitate global marketing campaigns to amortise the high R&D costs incurred. It is likely that no one material will dominate the market place for long periods, as has been the case until now. Nevertheless, advanced composite systems write a synergistic combination of materials families, as shown above, are currently meeting very stringent performance criteria in a range of high-tech applications and may become the preferred materials in many applications in the first decades of the next century.

Figure 2 shows examples of differences between existing and new MATERIALS as depicted by the Japanese Ministry of International Trade and Industry. A detailed functional and chemical classification of advanced materials developed carefully by

Figure 2: Existing and New Materials



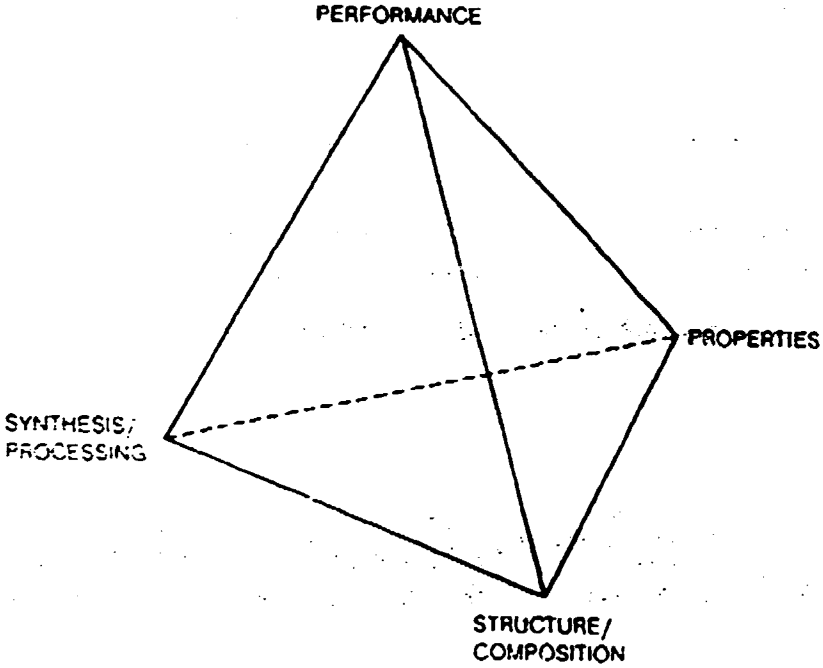
- **Organic Materials**: Materials composed of carbon compounds such as plastics (light-weight, workability, insulative)
  - **High-Performance Polymer**: Polymer possesses functions such as strength, conductivity and separation of necessary constituents from mixture, that are not found in conventional polymer materials.
    - **Engineering Plastics**: Plastics with such superior mechanical characteristics as heat resistance, stiffness and anti-abrasion. — Mechanical parts, structural materials for automobiles.
    - **Polymer Separation Membrane**: Polymer membrane for separating necessary constituents from gas and liquid mixtures. — Separation of hydrogen and oxygen enriched membrane medical use
    - **Photosensitive Resins**: Plastics which change physical properties and generate electricity by reaction to light. — Photoresist for IC board
- **Inorganic Materials (non-metals)**: Materials composed of inorganic compounds such as glass and porcelain (hardness, heat resistance, corrosion-resistance)
  - **Fine Ceramics**: High-performance inorganic materials with accuracy of highly refined synthetic powders, as opposed to so-called ceramic products such as glass and porcelain.
    - **Silicon Nitride and Silicon Carbonate**: High-purity silicon nitride and silicon carbonate. — Engine materials and artificial bones
    - **Balium Titanate**: High-purity titanium and balium. As insulating material with high resistance. — Ceramic condensers
    - **High-purity Alumina**: Aluminum oxide sintered at high temperatures by development of sintering technology and an auxiliary agent. — IC packages
- **Metallic Materials**: Materials composed of metallic elements such as iron and aluminum (strength, conductivity, ductility)
  - **New Metallic Materials**: Metallic materials which possess such new functions as expanding and contracting original form like rubber, depending on temperature change.
    - **Shape Memory Alloy**: Alloy such as Ni-Ti which can return to a given form at a selected temperature. — Pipe joints and core materials for brassieres
    - **Hydrogen Storage Alloy**: Metal alloy which stores and releases hydrogen and desorbs and absorbs heat at the time thereof. — Hydrogen cars, heat storage and transport systems
    - **Rare Earth Magnets**: Highly-coercive permanent magnets made of rare earth metals such as Sm and Co. — Headphones and small speaker motors
- **Composite Materials**: High-performance materials by combination of a plurality of materials like FRP (composed of carbon fibers and plastics) and FRM (composed of alumina fibers and metals).
  - **Carbon Fiber-reinforced Plastics (CFRP)**: Materials in which carbon fibers are used to reinforce plastics — Sporting goods, aircraft body materials

Source: K. Takeda, Basic Industries Bureau, MITI

2.1.3 The elements of modern materials science and engineering.

Modern[3] MSC has emerged as a coherent integrated scientific and technological approach to materials from a diverse number of fields ranging from its purely scientific roots in condensed-matter physics, sclid-state and synthetic chemistry to industrial R & D laboratories and practical engineering and manufacturing experience. The U.S. National Research Council has recently depicted the four main elements comprising MSC, namely structure and composition, properties, synthesis and processing, and performance, in the form of a tetrahedron shown in Figure 3 below.

Figure 3



Source: Materials Science and Engineering for the 1990's, U.S. National Research Council, Committee on Materials Science and Engineering, 1989, p.29

It is important to point out that this approach, which places at centre stage the interactions and close relationship between structure, properties, performance and processing, is both necessary and applicable to all classes of materials. Secondly, the field of MSC has a strong component in pure science which is coupled to a strong engineering and industrial base. That is, improvements in existing materials or the development of new materials, entail both a deep understanding of pure science and of the fundamentals of processing and fabrication technology, as is illustrated by the development of semi conductors, lasers, composite materials and super conductors. It follows, thirdly, that as we enter the 90's, new and improved traditional materials development, processing and manufacture will come to depend on the scientific and engineering base of MSC, rendering all other empirical and craft-related approaches across the materials spectrum grossly inadequate and obsolete. Fourthly, the need to examine the many fold aspects of materials

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[3] See U.S. National Research Council, 1989, op.cit., Ch.2 M. Kranzberg and Cyril Stanley Smith 'Materials in History and Society', Materials Science and Engineering, Vol. 37, No. 1, Jan. 1979. G.L. Liedl, 'The Science of Materials', Scientific American, October, 1986.

structure, composition, phenomena, characterisation, synthesis, and processing, involves the interaction of many hitherto specialised fields and descriptions, which are increasingly having to work together. All four areas have far-reaching consequences (1) for the mechanisms of incorporating scientific insight into the productive sphere, (2) the educational, infrastructural and industrial organisation requirements of the new materials age, (3) the global restructuring of basic industries and (4) the opportunities open to developing economies to enter, or remain, at various stages in the transformation of materials into useful structural and functional components and final products.

2.1.4 Materials science and engineering is multi-disciplinary

Materials science is now a multi-disciplinary 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. In any case, what is clear at this stage is that the nature and complexity of the problems in materials synthesis and processing is such that a joint simultaneous team effort across many disciplines, several professional staff and previously isolated research teams is now definitely required. Multi-disciplinary materials design, product development and processing capabilities are therefore becoming crucial at the level of the firm, the industry, the university, the research laboratory or the economy for that matter.

2.1.5 The central 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 micro-structure of materials, that is 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 a material follows will affect microstructure and thereby properties and performance in use. Hence, materials science and engineering have now merged. A related aspect to this is that whereas in the past processing techniques were largely non-scientific and empirically based, now the science content of not only the material but, significantly, also of materials processing technology in both traditional and new advanced materials has increased by a quantum leap.

Materials scientists, across the whole spectrum of disciplines and specialisations, are therefore 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 made for a close integration of the subject matter of materials science and engineering in terms of its pure and applied aspects viewed by necessity as a coherent whole. At the same time this has led to a fruitful feedback and cross-fertilisation between scientific understanding and the engineering problem of processing materials such as to control structure and improve performance, reliability and reproduceability 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 recent. Such new processing technologies (See Diagram 2) are being developed through the use of computer controls, sensors, process modelling, artificial intelligence, standards in process non-destructive testing etc.

Underlying the discovery of new materials with new properties and exhibiting new phenomena (e.g. the high-temperature super-conductors in 1987), the improvements in the control of structure, composition and, hence, properties of known materials, and progress in the development of materials processing and manufacturing technologies, lies synthesis. Synthetic capabilities in the chemical and physical combination of atoms and molecules to form materials and, and its coupling to characterisation and analysis of properties, processing and manufacture is emerging as a crucial determinant of progress in pure materials research, rapidity of translating basic research to commercial application and the rate of technological change across national industrial branches and economies. Although the synthesis element of MSC necessarily retains a large scientific base, it is, nevertheless, organically connected to the processing and manufacture of solid materials. For, not only does the choice of synthetic reactions, as in the preparation of high purity powders for advanced ceramics fabrication, influence subsequent processing paths, but also modern fabrication technologies involve the merging of the synthesis and processing stage into a simultaneous process, as in injection molding of plastics. Thus, materials synthesis, processing, fabrication and manufacturing are merging in response both to forces internal to MSE, and, to pressures emanating from the evolution of new production technologies, as well as the ever increasing need to transmit, fast and efficiently, materials pure research into industrial and military application.

At present, a major constraint in the diffusion of advanced materials into a wide range of technologies and industrial applications is the ability to process raw or synthesized substances into reliable, high-volume, low cost useful forms, such as films, wire, components, devices and structures entering complex engineering systems. This is no more evident than in advanced structural ceramics, composites, and the new high-temperature superconductors. But more than this, it is becoming clear that technological competence in materials processing and fabrication is the critical component in international competitiveness of national industrial structure and industrial branches engaged in traditional and high-technology activities. Such processing capabilities facilitate more rapid translation of research results to commercial applications, and 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 Japanese and South Korean experience, where manufacturing capabilities and associated materials processing technologies have been developed in parallel, to great advantage in terms of innovation and global competitive advantage.

2.1.6 The integration of materials producers and users

Increasingly, the synthesis, design and processing of a material must be integrated with the design and manufacturing path of the end-user. Materials design, component, sub-assembly and computer-aided product design engineering and manufacture are merging and require close integration and iterative interaction. In some cases, the design and manufacture of the material and of the component or end-product is a simultaneous process involving large teams of specialists as in advanced composites applications in aircraft or automobiles.

2.2 New and improved materials in the transition to Post-Fordism.

2.2.1 From Fordism to Post-Fordism

In the last 15 years a major discontinuity has appeared in the post-war pattern of mechanisation and work organisation which was based on inflexible, mass-production techniques. Industry is undergoing fundamental restructuring in the process of which there is a transition away from Fordist production practices characterising the post-war period toward increased flexibility. The emerging paradigm constituting a break from the characteristics and practices in industrial organisation, social relations and institutions associated with the previous era, can be broadly termed as Post-Fordism.

Fordist mass production methods employ the principles of increasing division of labour, fragmentation of tasks, mechanisation of tasks and employment of dedicated 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, admittedly, authoritarian and hierarchical labour management system in which labour skill, initiative and creativity are mostly eliminated, requires uninterrupted, high volume output of standardised products aimed at mass markets. Production here is supply driven; and utilises substantial work in progress and finished good inventories, to offset faults and quality problems and to meet fluctuations in demand. Dedicated plants and production lines make sense in conditions of very high volume, small product variety, and long product life-time and a stable macroeconomic environment in which incomes and tastes can accommodate what is emerging out of mass-production lines.

Market demand has become increasingly fragmented and unstable with consumer preferences necessitating higher quality, greater variety, low volume production of products with shorter life-cycles. Hence the inflexible manufacturing methods and accompanying inventory systems characterising Fordist production lines have become increasingly unsuitable in conditions of product differentiation, consumer sophistication, and fast changing market circumstances. Firms increasingly need to be more flexible and in close contact with the market for recognizing and speedily responding to changing demand patters. Greater variety needs to be produced in small lot sizes.

New patterns of work organisation and methods of manufacturing are emerging[4] and are diffusing throughout manufacturing in IAC's. What can broadly be described as the Just-in-Time concept of production evolved in Japan during the late 50's-70's, as an attempt, at first, to reduce inventory costs. As is currently employed, JIT lays emphasis at the demand side of the market, with close integration to customer preferences, an ability to offer large product variation and choice to consumers, and fast delivery times. Thus production is driven by a fragmented demand, and hence requires flexible patterns of work organisation and machines in order to be able to respond in a cost effective manner. Flexibility in output requires a multiskilled labour force operating in the framework of a flexible manufacturing process capable of fast, efficient changeovers to different products of small lot sizes. In this scheme of work organisation, labour is given more autonomy and responsibility in the context of more skills and multitask competence, and is paid in accordance to skill and not task as before. The central feature of the new system is a shift to multiskilling and flexible working practices of the labour force. this facilitates the reorganisation of production so as to dramatically reduce inventories of work in progress and final goods, and to introduce a zero-defect policy which is crucial to flexibility and the very functioning of JIT. Quality control now is the responsibility of workers at the point of production and requires decision making and rectification of errors by the worker. Flexibility, responsibility and quality control thus go hand in hand.

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[4] See R. Kaplinsky, 'Restructuring Industrialisation', IDS Bulletin, Vol.20, no.4, 1989.
______________, 'Restructuring the Capitalist Labour-Process', Cambridge Journal of Economics, Vol.12, no.4, 1988.
______________, 'Electronics-Based Automation Technologies and the Onset of Systemo-facture', World Development, Vol.13, no.3, 1985.
See R.J. Schonberger, 'Japanese Manufacturing Techniques', Free Press, 1982.
______________, 'World Class Manufacturing', Collier Macmillan, London, 1986

Evidence suggests that organisational change per se can produce great gains even with existing technologies, that it is a prerequisite to introducing automation technologies, and that most of the gains derived from new technology owe their origins to new patterns of work organisation, management-labour relations and flatter hierarchical structures.

Such trends in terms of skill requirements of the labour process and the primacy of organisational and managerial change accompanying this transitional conjuncture, contain both threats to developing economies where skilled labour is in short-supply, and opportunities to those economies and sectors which can appropriate new work practices as the basis of incremental innovation and enhanced efficiency in production for the domestic or the world market, without recourse to expensive flexible automation technologies. This is especially so in designer-dominated sectors such as clothing, footwear, and furniture, where distinct possibilities exist for horizontal inter-firm collaboration, the sharing of research, development, marketing or designing costs and new forms of state and local-government collaboration with private industry, as the overworked experience of the 'Third Italy' illustrates, and the new Cyprus industrial strategy[5] aims for.

Of course, new forms of inter-firm relationships are a prevalent feature of the emerging Post-Fordist paradigm, in part due to the new market and competitive circumstances, and in part due to the technological and organisational features associated with the spread of flexible automation technologies in manufacturing. For example, materials, components and sub-assemblies suppliers are necessarily forging greater two-way vertical linkages with user and final-assembly manufacturers due to both design interactions and technological requirements of the production process, such as are introduced by the trend towards near-net-shape manufacture and the consequent elimination of various processing stages and assembly operations. Final assemblers cultivate and upgrade a small select group of suppliers which are then encouraged to innovate and participate in the quality drive and product design and renewal of the user firm. The recent trend towards modular manufacturing reinforces these vertical forms of collaboration between suppliers and user firms, while leading to enhance bargaining power on the part of materials and component suppliers. Thus the role of suppliers is emerging as paramount in the new manufacturing era and the diffusion of new best-practice techniques across traditional and new sectors, in both developed and developing economies. A further complication is that the new circumstances necessitate location of plant close to the market, while the employment of JIT organisation of production implies the need for suppliers to be in close physical proximity to the user firm. These observations raise the issue of the conditions which need to be fulfilled for an enlarged role of developing economies in the 1990's, as suppliers of materials, components and sub-assemblies to domestic or regional industry, and the world market. An economy lacking an appropriate, and high quality, network of suppliers may be eliminated from direct investment or global sourcing consideration while, on the other hand, an investing firm may wish to create from scratch and cultivate its own network of local input suppliers. At the same time, the absorption of new best practice techniques by domestic industry implies the creation of appropriate networks and collaborative arrangements with local or regional suppliers.

The foregoing highlight the need for a closer look at the role of materials supplies in the new manufacturing conditions, and it is to this that we now briefly turn.

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[5] See R. Murray, et.al., 'Cyprus, industrial strategy: report of the UNDP/UNIDO mission', Brighton: IDS, Univ. of Sussex, 1987.

2.2.2 Materials in the transition of IAC's towards post-Fordist industrial organisation

It is in fact wrong to analyse materials issues in a vacuum, as if organically disconnected from the socioeconomic, scientific and technical transformation of industrial capitalism. The process of transition of IAC's from mass-production techniques to more flexible patterns of production are integrally linked to the search for and delivery of a vast array of new materials. The emerging pressures for quality and reliability from the side of the consumer <u>and</u> of the manufacturer could only be met by an increasingly capable MSC whose philosophy was directed towards meeting the needs of end users for flexibility and higher performance specifications offering high marketing premiums in the market place.

The vastly increased ability of MSC in recent years to provide numerous new and improved materials options to end-use designers, and the capacity to synthesize entirely new advanced materials tailor-made for specific high performance applications in aerospace microelectronics, telecommunications, weapons systems and automobiles, has coincided with the emergence of the need for great flexibility at the level of consumption and production. This organic integration of the materials producing sector with the needs of the materials using sectors as an enabling technology facilitating and meeting the needs of the transition toward post-Fordism both at the level of the radically altered conditions in the market and at the level of new advanced production technologies has been a necessary and inseparable aspect of the restructuring of industry and its shift towards high-value added knowledge intensive production. Yet this silent revolution in materials production and use in the restructuring and reorganising of the industrial base of mature economies has received scant attention in the literature, and constitutes a large gap in our understanding of the new manufacturing era and its global ramifications. Throughout the 1970's and 80's there has been an ever greater integration and iterative interaction between the design and manufacturing process of new materials and end-products incorporating them. The emerging pressures of the global market place, the placing of the concept of design for manufacture at centre stage, the need to meet reduced product life cycle and fast product renewals, and the clear trend towards world class manufacturing and its attendant employment of CIM, JIT and TQC, ensures that materials issues increase in importance both at the design-manufacturing phase and in terms of the need for careful total materials management in each enterprise. In fact, the arrival of a proliferation of new and advanced materials necessitates the use of CAD/CAM in the user-industries, and conversely, the employment of such systems facilitates new design and production concepts which make use of the vast array of new properties on offer. Further, the computerised materials database is rapidly becoming the critical element in CAD, finite element analysis and its link to Computer-Aided-Manufacturing and Computer-Aided-Engineering, especially in the context of a move towards CIM by the firm.

The advent of advanced materials, fast on the heels of the microelectronics revolution and diffusion, and, increasingly, linked to it, will further complicate the restructuring process under way in IAC's, further undermine traditional sources of comparative advantage in the Third World in raw and semi-processed commodity production, and radically alter the conditions for global location of industry, licensing and transfer of technology and the sourcing of materials and components in comparison to the recent Fordist patterns on an international scale. It is thus clear that the advent of new advanced materials and information technologies closely linked to the restructuring process of IAC's and socio-technical transition to Post-Fordism, have altered the world industrial landscape almost unrecognisably in the 1990's, offering new options and new dangers to developing economies, which have not yet been adequately identified and analysed in a coherent, comprehensive framework.

3. PRIMARY COMMODITIES, BASIC MATERIALS INDUSTRIES AND DEVELOPING ECONOMIES.

3.1 The experience of the primary commodity sector.

3.1.1 The continuing importance of primary commodities for LDC's.

The value of non-fuel primary commodity exports as a percentage of total developing country exports has fallen from 55.9% in 1970 to 25.9% in 1984, while that of manufactures has risen from 24.9% to 40.1% and petroleum from 19.2% to 34% over the same period, with considerable variations between regions, as shown in Table 1. Clearly, the rising importance of manufacturing and fuel exports bears a large part of the responsibility for the declining dependence of developing countries as a whole on commodity exports. Factors operating on the supply, demand and prices of commodities have also contributed to this, and they are briefly examined below.

These figures though mask considerable variation between countries. It is a sobering fact that despite progress on manufacturing exports, the majority of developing economies still remain largely dependent on primary commodity production and exports for a major part of their foreign exchange earnings. The primary commodity export sector, with its varying, but generally low degrees of downstream processing, has remained for most developing countries the backbone of economic activity and their development process.

Recent UNCTAD[6] calculations, indicate that agricultural and mining production is the single most important component of GDP for all developing countries, except the fast growing manufacturing exporters, and that for most, the share in GDP is more than 30 per cent as compared to less than 10 per cent in the developed market economies. Moreover, for more than 80 developing countries the share of primary commodities in total export earnings is above 50 per cent. In many cases, and especially for low income countries, it is also accompanied by a high degree of export concentration on one or two primary products. In 1986, the share of non-oil primary commodity exports in total exports of the 42 least developed countries, according to UNCTAD, was 65%. One group of problems often cited for the disappointing performance of commodity exporters relates to commodity export and price instability, slow or declining growth in real export earnings and/or volumes, and a long run deterioration in the real prices of their commodities. In 1986, the barter terms of trade for non-fuel primary exports were below half the high levels in 1950, according to the World Bank, which also predicts that by the year 2000 non-fuel commodity prices will only be 8 per cent higher in real terms than in 1986 and hence 25 per cent below 1980 levels. Following the relatively strong market position of commodities in the 1970's accompanied by a large expansion of capacity, the 1980's have witnessed massive overcapacity and over-supply in many commodity markets, coupled with a slump in prices until recently, as shown in Figure 4.

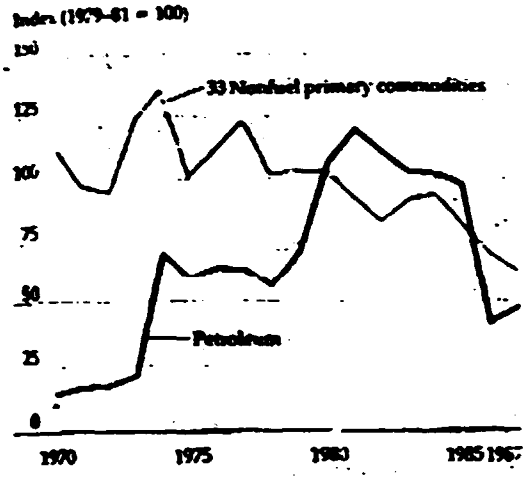
Table 1. SHARE OF PRIMARY COMMODITIES AND MANUFACTURES IN TOTAL EXPORTS, 1970, 1980, and 1984

	Exports, fob, (billion current US dollars)			Percentage of Total Exports		
	1970	1980	1984	1970	1980	1984
DEVELOPING COUNTRIES						
Primary Commodities						
America	11.2	45.1	43.1	65.9	43.3	38.2
Africa	8.3	23.2	18.3	70.3	23.8	30.4
Asia	9.3	47.4	44.2	43.1	21.1	18.7
Others[2]	1.9	7.3	7.9	44.2	27.9	28.1
Total	30.6	23.0	113.5	55.9	27.2	25.9
Petroleum[3]						
America	4.1	41.5	43.8	24.1	39.9	38.8
Africa	1.8	50.2	33.8	15.3	51.6	56.1
Asia	4.5	88.5	69.9	20.8	39.4	29.6
Others[2]	-	1.4	1.1	-	5.3	3.9
Total	10.5	181.6	148.6	19.2	40.2	34.0
Manufactures[4]						
America	1.7	17.5	26.1	10.0	16.8	23.1
Africa	1.7	23.9	8.1	14.4	24.6	13.5
Asia	7.8	88.6	122.2	36.1	39.5	51.7
Others[2]	2.4	17.5	19.0	55.8	66.8	68.0
Total	13.6	147.5	175.4	24.9	32.6	40.1
Total Exports						
America	17.0	104.1	112.9	100.0	100.0	100.0
Africa	11.8	97.3	60.3	100.0	100.0	100.0
Asia	21.6	224.5	236.3	100.0	100.0	100.0
Others[2]	4.3	26.2	28.0	100.0	100.0	100.0
Total	54.7	452.1	437.5	100.0	100.0	100.0
INDUSTRIAL MARKET ECONOMIES						
Primary Commodities[1]	49.0	241.9	210.9	22.4	19.9	17.6
Petroleum[3]	7.6	90.3	95.4	3.5	7.4	7.9
Manufactures[4]	162.1	884.8	894.0	74.1	72.7	74.5
Total Exports	218.7	1,217.0	1,200.3	100.0	100.0	100.0

1. SITC 0 plus 4 and 68 (includes non-ferrous metals)
2. United Nations data for other developing countries is obtained as a residual figure and does not necessarily reflect the actual export performance of the countries/areas involved
3. SITC 3
4. SITC 5 to 19 excluding 68 (excludes non-ferrous metals)

Source: Commodity Trade and Price Trends, World Bank, 1987-88 edition, Table 1

Figure 4: Real Commodity Prices 1970-1987



Note: Real prices are annual average nominal prices in dollars, deflated by the annual change in the manufacturing unit value index (MUV), a measure of the price of industrial country exports to developing countries.

Source: World Bank, World Development Report, 1988, p.25

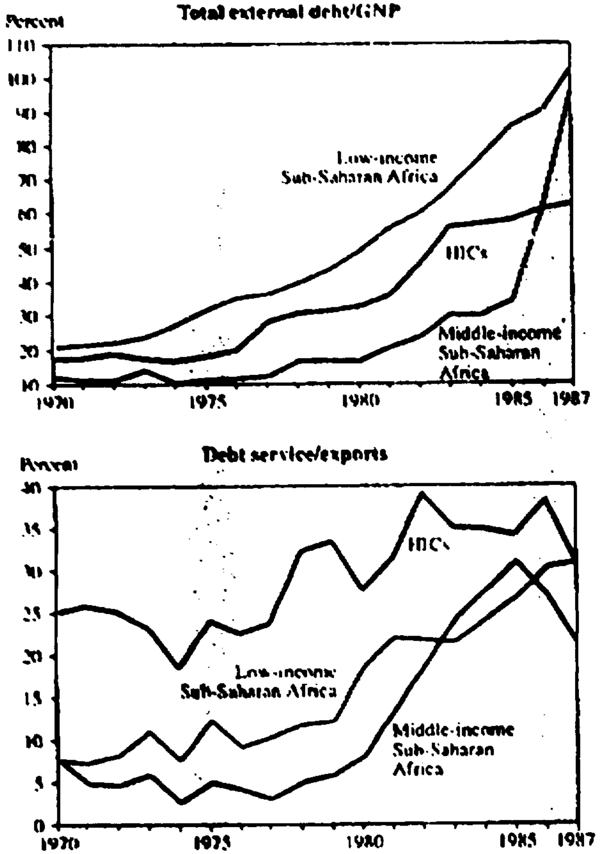
Exchange rate movements exacerbated these trends, leading to severe problems for many developing countries, in particular in sub-Saharan Africa where import capacity and government revenues and expenditures have been dramatically curtailed and per capita income has been dropping since 1980.

The worst hit region was sub-Saharan Africa (SSA), where the combination of falling prices and stagnation in primary export volumes, led to a sharp decline in real purchasing power. In contrast, the volume of primary commodity exports increased in East Asia, counteracting the falling prices and maintaining purchasing power. In Latin America and South Asia purchasing power declined due to insufficient growth in the volume of primary export in the 1980's.

Declining commodity prices and export revenues have led to an increasing need for external financial borrowing and to a rising indebtness of developing countries in the 1980's. Figure 5 shows the trend of the ratio of external debt as a proportion of GNP and debt service obligations as a percentage of total exports for sub-Saharan African and the 17 Highly-Indebted-Developing Countries (HIC's) since 1970. The total debt of sub-Saharan Africa increased from $6 billion in 1970 to $134 billion in 1988, such that by the late 80's it amounted to three and a half times the regions export earnings and almost equalled its GNP, as compared to Latin American debt which is only 59% of GNP. While sub-Saharan debt has been growing faster than any other region, especially in the 1980's, the export structure has remained relatively unchanged since the 1960's, displaying heavy reliance on primary commodities, which accounted for 93% of total export earnings in 1970 and 88% by the mid-80's, and heavy concentration on markets of the European Community.

Debt service obligations actually paid amounted to 27% of SSA exports on average between 1985-88, with low income economies carrying a higher burden of 30%. The severest difficulties are faced by the low-income SSA with debt ratios double those of middle-income HIC's and three times those of low-income Asian countries. But middle-income a per capita GNP a third of the latter, and a high export concentration on few primary commodities.

Figure 5 External debt of Sub-Saharan Africa and highly indebted countries, 1970-87



Note: HICs refers to the group of 17 highly indebted developing countries, listed in World Bank 1988b, of which two are in Sub-Saharan Africa. Total external debt is outstanding and disbursed long-term debt, short-term debt (1977-87), and IMF credit. Debt service is interest and amortization for long-term debt. Exports are goods and services. Percentages are based on debt in current dollars.
Source: World Bank data.

Table 2: Selected developing economies of the ESCAP region. Indicators of the weight of indebtedness

	Debt outstanding/GNP		*Debt outstanding/exports (Per cent)*		*Debt-service ratio*[a]	
	1980	*1986*	*1980*	*1986*	*1980*	*1986*
Republic of Korea	49.3	47.4	131.8	107.5	12.2	16.7
Indonesia	27.9	58.5	94.1	278.1	7.9	29.3
India	11.9	19.1	157.3	276.1	8.8	10.1
Philippines	49.4	93.6	217.4	326.3	7.2	18.3
Pakistan	38.7	39.0	329.9	343.2	19.7	26.8
Thailand	25.1	44.7	96.3	154.0	5.0	16.7
China	2.8	8.8	39.2	75.3	3.4	7.9
Malaysia	21.9[b]	76.2[b]	35.0[b]	120.6[b]	2.5	13.7
Bangladesh	31.5	50.6	404.0	729.2	7.8	25.1
Sri Lanka	48.3	64.4	143.5	...	6.3	...
Burma	25.9	45.2	268.7	846.0	20.1	55.4
Papua New Guinea	29.2	95.6	66.1	192.4	3.6	12.4
Fiji	23.7	33.0	46.8	75.6	3.4	10.0
Nepal	10.4	29.0	85.0	225.4	1.7	9.2
Samoa	...	68.4	232.5	307.3	18.0	24.0
Maldives	108.2	121.2	39.5	...	0.4	...
Solomon Islands	16.7	64.8	22.8	...	0.1	...
Vanuatu	...	...	...	223.5	...	2.1

Source: World Bank, *World Debt Tables: External Debt of Developing Countries, 1987-88 Edition*, vol. II, *Country Tables* (Washington, D.C., 1988).

[a] Public and publicly guaranteed debt. [b] Excluding short-term debt.

Table 2 displays indicators of indebtness of selected ESCAP region economies between 1980 and 1986. One consequence of the decline or stagnation of official aid flows to the ESCAP region in the decade leading to the mid-1980's, was the rapid expansion in commercial debt. Although the Republic of Korea was the biggest debtor in the region, large current account surpluses since 1986 enabled it to make large reductions in external debt. On the other hand, India's debt to export ratio rose from 157% in 1980 to 276% in 1986 while the debt service ratio doubled to 18%. Similar trends are also visible for a number of the least developed economies in the region. Other major debtors include China, Indonesia, the Philippines and Thailand, with varying severity and capacity to ameliorate the use of the relevant debt ratios in the last few years.

The net outflow of large amounts of foreign-exchange earnings to meet external debt obligations has had serious repercussions on domestic investment, growth and import capacity for many developing economies in the 1980's. Declines in per capita incomes have combined with reduced expenditures on education and social programmes and an inability to maintain a deteriorating infrastructure and industrial capacity. Despite efforts in recent years aimed at rescheduling and refinancing of debts, little has been achieved in ameliorating the continuing and growing debt levels and debt servicing obligations. Measures on debt relief or debt reduction together with availability of low cost external finance are therefore critical to many debtor developing economies in the short- to medium-run. Nevertheless a long term solution must involve, crucially, a restructuring and diversification of the commodity export sector together with improved market access and trade liberalisation measures in IAC's and other regions.

Given the persistent importance of primary commodity production and trade to several developing country groups, such as (overlapping of course) SSA, the 42 least-developed-economies, and the 66 African-Caribbean-Pacific Group of States in the Louré Conventions, efforts to strengthen their presence in, and improve the functioning of existing commodity markets, and increase the value-added before exports are indeed relevant in the short- to medium-run. Nevertheless, a central message of this paper is that solutions to the endemic problems faced by the commodity sector and associated indebtness of developing economies must take into account the fast changing materials and manufacturing scene. For, the survival and trade prospects of many such economies in the 1990's depend on the availability and adequate provision of funds for increased education and training expenditures, the upgrading of scientific, technological, engineering capabilities and infrastructure and productive investment which meet the requirements of new and improved traditional materials production and use.

3.1.2 The need to reassess commodity strategies in the 1990's

As we enter the 1990's, developing economies face a pressing need for a re-evaluation of traditional strategies on commodities, including downstream processing and commodity metal and chemical production for the world market, which remain steeped in the circumstances and experiences of the post-war period and, more recently, the historically limited but impressive successes of the 1970's. Throughout the 1980's there has been a prevalent tendency for knowledge intensity in production to increase in qualitative jumps, and, the global intensification of competition and rapidity of technical change has resulted in accelerating product and process obsolescence, faster product renewal and a significant reorientation of marketing strategies. Accompanying the slow shifts in industrial structures is the spread of rapidly evolving information technologies in the production base leading, on the one hand, to a shrinkage of minimum efficient scale and erosion of barriers to entry in some sectors, and, on the other hand, the erection of greater barriers and enlargement of scale economies in others, due to learning by doing vast scientific content of production and large research expenditures required.

As if coming to grips with such difficulties was not enough, the trends and tendencies identified in this paper as emanating from the revolution in materials science and engineering further complicate matters and usher in new unknowns and imperatives. Primary producing developing economies are no longer inserted in the world division of labour on the basis of large scale commodity provision to the needs of mass-production and mass consumption in IAC's. Rather, they find themselves enmeshed in a world economy undergoing fundamental restructuring and transition to post-Fordist methods of production, and patterns of consumption in the context of an emerging new socioeconomic and technological paradigm, embracing the triad of information, materials and bio-technologies. In this transition, the role of new, improved traditional and advanced materials has been, and unquestionably will continue to be highly significant. As demand patterns, resource requirements and processing facilities are reordered and shifted internationally, so will, therefore, change the role and importance of traditional suppliers of raw and semi-processed mineral and agricultural raw materials. The issues, though are broader, and go far deeper, than the mere evaluation of Third World prospects in terms of future demand projections for traditional ores, commodity metals or agricultural products.

Not only is it exceedingly prudent for developing economies to ask whether it is feasible and advisable to remain in specific commodity production as a long-run proposition, but also to reassess the wisdom and the conditions under which they should remain or enter downstream processing in the 1990's. Whether an economy is to remain or exit from a specific commodity, the fact remains that it still has to establish an institutional and manufacturing base that can survive and prosper in the scientific, technological and global market conditions of the 1990's. The central point is that the materials sector is now steeped in new scientific and engineering capabilities, with new best practice technologies that can be directed to meet basic needs more efficiently, and/or meet the quality, reliability, and low cost reproduction requirements at all stages of processing and semifabrication demanded by materials and components users. The acquisition of the attendant engineering, scientific, educational, testing and quality control, and infrastructural capabilities thus becomes a vital concern for developing economies, attempting to meet materials for small scale industry embracing flexible specialisation or flexible mass manufacturing, producing locally or sourcing globally. Hence materials issues and strategies are inseparable from the process of the global restructuring of industry and the evolving conditions for the location of labour- and skill-intensive activities across manufacturing. It is to this we now turn.

3.2 The restructuring of industry in the period 1970's-1980's

3.2.1 Restructuring of industry within IAC's and redeployment to LDC regions in the 1970's

Since the 1960's, progress has been made in the processing before export of domestically produced agricultural and mineral raw materials in developing countries, in part of a deliberate result of a resource based industrialisation strategy. The higher degree and greater global share of processing activities undertaken in LDC's has, of course, also resulted from underlying economic forces. Declining ore quality, escalating energy prices, increased environmental regulations and compliance costs, and higher labour costs in the 1970's in IAC's meant that energy-rich, resource-rich developing regions (together with Canada and Australia in some minerals) became increasingly attractive for replacement and expansion of capacity as the location of smelting capacity in IAC's was rendered increasingly uneconomic. This has also been the case for petrochemicals, synthetic figures and other energy extensive basic industries. This is not the place for a detailed sectoral examination of the trends in organic and inorganic minerals processing capacity within OECD economics since the early 1970's. Suffice it though to point out that this process whereby declining sectors in the industrial structures of IAC's in labour-intensive or energy and raw material intensive activities began to be restructured and redeployed to LDC's in the 1970's, was welcome by UNIDO as broadly in line with changing patterns of comparative advantage in the context of the internationalisation of production. Increasing domestic raw material capacity in LDC's in the line with long-run development objectives together with the redeployment of processing industries and labour intensive branches, such as textiles, shoes etc, to LDC's was viewed by UNIDO as part of converging interests of LDC's, MNC's and governments in IAC's. Moreover, such global industrial restructuring and redeployment was part of the process of increasing the share of LDC's in global manufacturing to 25% by 2000, as the Lima declaration envisaged. Nevertheless this happy coincidence of interests accompanying a frictionless restructuring and redeployment of industries from IAC's to LDC's soon faced difficulties. Over capacity appeared in several sectors in the early 1980's, there were growing voices of concern over import penetration of manufactures from NIC's and protectionist barriers began to be erected to protect IAC's basic industries facing severe difficulties. The restructuring of industry in the 1980's introduced new unknowns into the process of global redivision of labour and the expulsion of basic and declining branches from IAC's.

3.2.2 The diffusion of microelectronics-based automation technologies in the 80's.

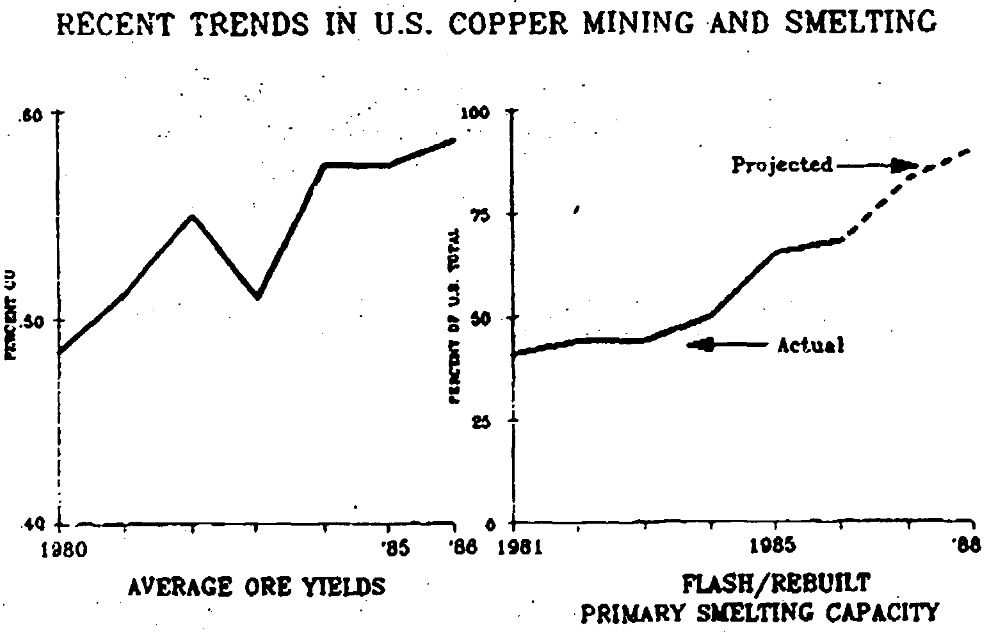
The industrial structure of IAC's is shifting towards high growth, high technology, knowledge intensive branches of industry with large intersectoral linkages to the rest of the economy. Mass production and batch-production industries with the capital goods and engineering sectors are automating and reorganising their production lines within the incorporation of flexible manufacturing techniques. Mature, declining sectors are being modernised by the adoption of microelectronics based automation technologies such as (a) they are beginning to retain their cost competitiveness within the industrial structure of IAC's and (b) acquire higher potential for future incremental innovations and productivity gains to maintain their competitive advantage. The difference between technologically progressive and stagnant industries may be becoming blurred in fact.

These developments are beginning to erode the traditional comparative advantage of LDC's in low wage, unskilled segments of the production process or labour intensive industries. Wage cost differentials have seized to be a determining influence in offshore location decisions of MNC's as labour cost assume less importance in total production costs and wages rise in LDC's. It is likely that labour intensive activities may in fact be retained within IAC's in the foreseeable future. In addition, the technological upgrading and automation of mineral processing and fabricating activities may in fact retard the process of expulsion and redeployment of basic industries from IAC's to LDC's. Hence, new technologies are introducing a fundamental break from the experience of the 1970's and may eventually lead to a major retrenchment of MNC's location and sourcing in LDC regions, or at least a realignment of the importance and role hitherto ascribed to different LDC regions and countries.

3.2.3 The restructuring of basic materials industries in the 1980's.

Looking at the restructuring process of basic industrial branches within the industrial structure of IAC's in the 1980's, a number of interesting tendencies can be identified. Large segments of outdated and inefficient productive capacity have been shut down, while remaining capacity has been modernised and technologically upgraded (see Diagram 3). This technological renewal and rejuvenation of traditional smelting and processing capacity has resulted in a smaller but more efficient and competitive capacity, exemplified by the current healthy state of US copper and primary aluminium industries. Although retaining a certain portion of domestic capacity in traditional 'smoke-stack' industries is deemed desirable, a consensus seems to be emerging that economic, and political, pressures are making developing regions, and Australia and Canada, from which the requirements of IAC's are to be met on the principle of least cost sourcing. At the same time, as commodity metal and chemicals production is being relinquished and/or relocated abroad, firms in these industries have began a discernible strategic move downstream, into high-value added processing and fabrication of specialty metals and chemicals aimed at specific market niches. This of course is in line with the tendencies of the transition to post-Fordist industrial organisation as it permeates and appropriates the production of intermediates entering into final goods. A related feature of these ongoing processes is the forging of close relationships between metals, chemicals, ceramics and glass producers and their customers in industry, with the aims of meeting the latters' more stringent specifications and property requirements in specific applications, thus also fending off competition from competing materials of course. Together with the move to downstream vertical integration, a number of firms in Japan, Europe and the USA, have began to diversify into related business, and into advanced materials, with varying degrees of success. In fact, the tendency towards the in house acquisition of the multi-disciplinary scientific and engineering capabilities for a multi-materials competence in conditions in which barriers between traditional materials markets are eroding, marked by significant interpenetration of materials in end-uses, is a major feature of the current transition. Accompanying the transition towards diversification and entry into new material competences is the tendency to form joint ventures and technology licensing agreements, together with mergers and acquisitions, across national boundaries in virtually all new materials.

Diagram 3: Recent Trends in U.S. Copper Mining and Smelting



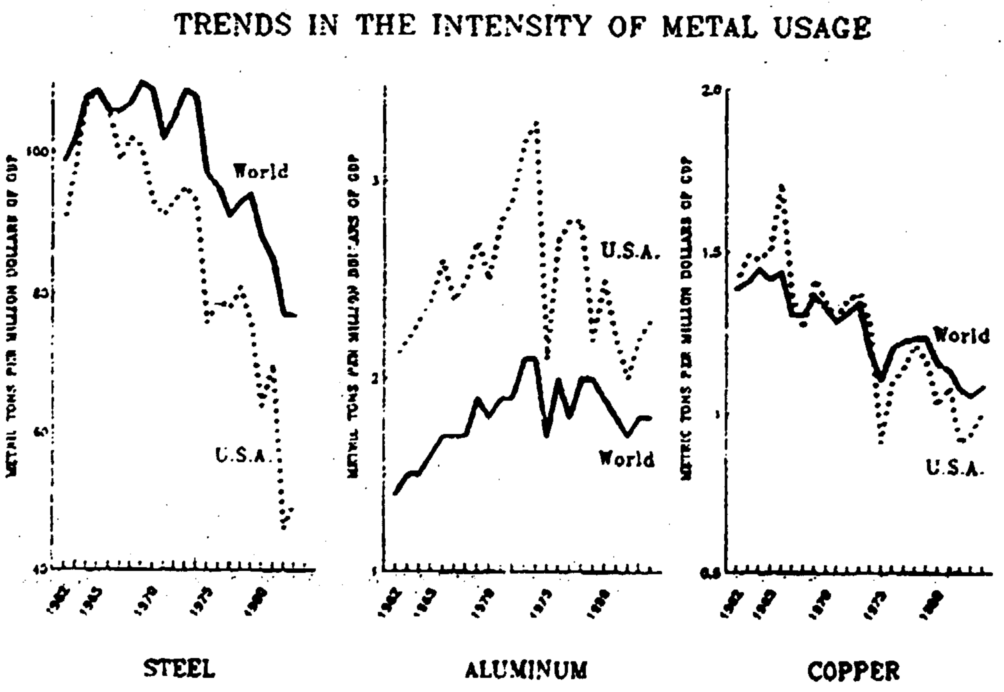
Source: L.J. Sousa, Problems and Opportunities in Metals and Materials, U.S. Bureau of Mines, 1989.

National and international commodity policy is therefore necessarily enmeshed in these structural transformations of the materials producing sectors, the emerging business strategies influencing global location and sourcing, and the impact of new technologies and organisational change on the materials processing and fabrication stages themselves as well as on the materials using industries. Neglect of these factors can only result in dangerously misleading policy conclusions. It is within such a framework that we must locate the potential and opportunities for developing economies in traditional and new advanced materials.

3.2.4 Traditional versus advanced materials

The restructuring process of the IAC's is also reflected in the interplay between the use of (improved) traditional and advanced materials in industry. Although the adverse impact of substitution and technical change is not a new phenomenon for industrial raw materials, the observed marked declines in intensity of use since the early 1970's may signal the outset of irreversible and structural forces acting on the demand side. Sectoral shifts in the product composition of national output away from materials intensive sectors, and declining material ore per unit of final output, which is the result of substitution and technological and organisational change in manufacturing, have combined to reduce intensity of use. This process may continue in the 1990's and indeed accelerate as a wide range of natural fibres, sugar and metals such as aluminium, steel and copper face greater substitution from the diffusion of advanced materials, especially engineering polymers. Attempting to quantify the impact of advanced materials on traditional materials in the 70's and 80's, comes up against insuperable data availability difficulties which have yet to be overcome. At the same time attaching specific numbers to future projections on specific commodities and advanced materials is fraught with difficulties and ambivalent trends in the underlying factors. Although advanced materials and minor metals are expected to display very high growth rates over the next decade, projections on advanced materials are nothing more than informed guesses and vary by orders of magnitude between sources. Projections for U.S.A. and Japan for the year 2000, are given in Figure 6.

<u>Diagram 4: Trends in the Intensity of Metal Usage</u>

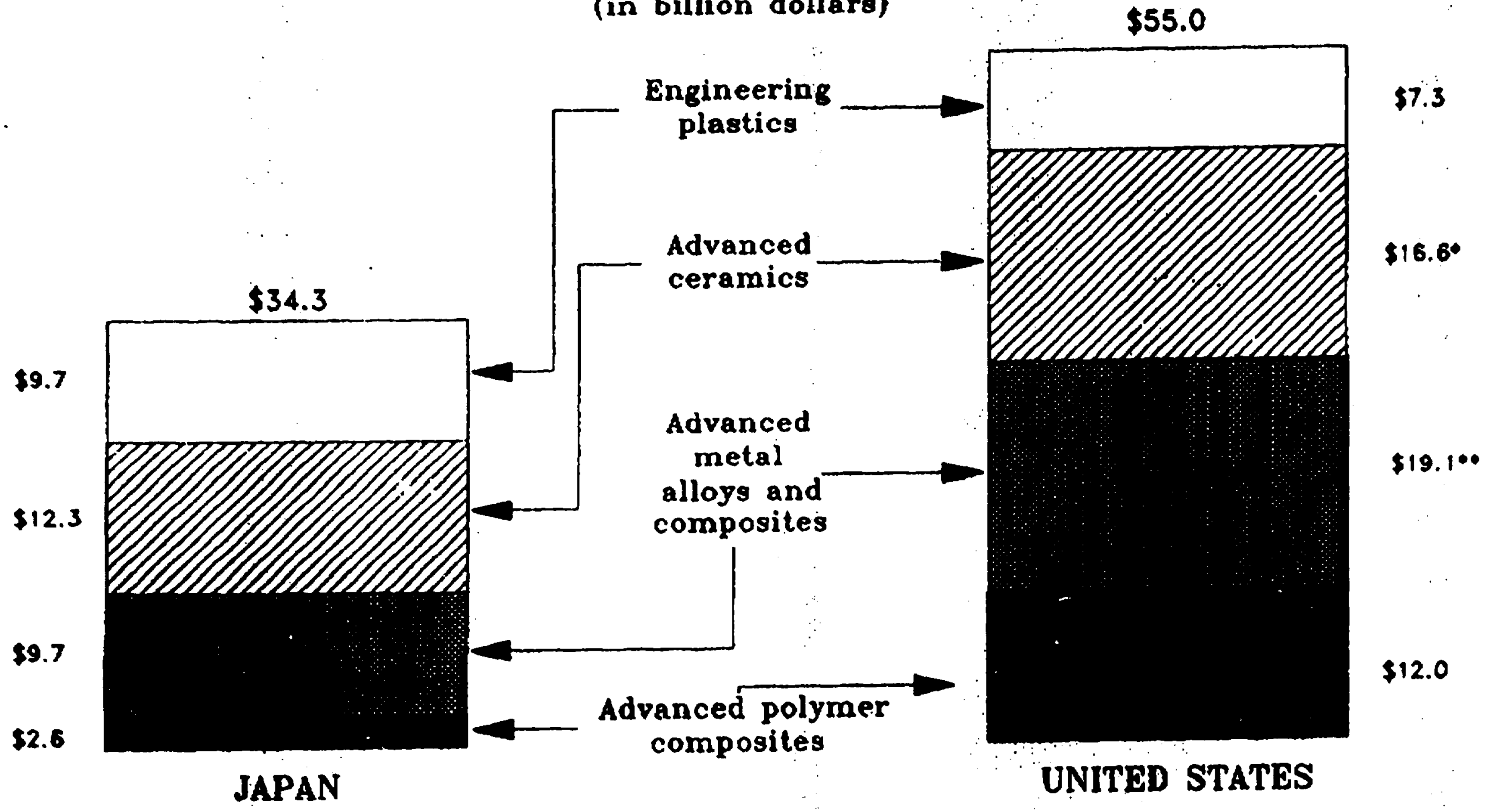


Source: L.J. Sousa, U.S. Bureau of Mines, 1989.

Thus, trends in intensity of use and demand for specific raw and semi-processed commodities in the 90's and beyond depend on the complex interplay between a number of factors: the growth of economic activity in developed and developing economies; sectoral growth rates and the formation of fixed capital; the evolution of consumer tastes and environmental concerns; technical change and potential further economisation in material use; defensive R & D and marketing in many commodities

Figure 8: ADVANCED MATERIALS: FORECAST MARKETS IN THE UNITED STATES AND JAPAN IN THE YEAR 2000

(in billion dollars)



*Includes fiber optics.

**Includes specialty metals.

Source: L.J. Sousa, US Bureau of Mines, 1988 utilising the insight of MSC (eg. natural rubber, cotton, wool, aluminium, steel, nickel, zinc); and the degree of market penetration by advanced materials in the 1990's. The competition between traditional but greatly improved materials and advanced materials will intensify in the next few years and the outcome cannot be predicted. Existing materials can of course form an alliance with advanced materials in matrix composites, while one material is unlikely to displace another wholesale given the preference of manufacturers to employ diverse materials in synergistic combinations in complex systems such as aircraft or cars. Apart from processing, cost, reproducibility, awareness, inertia and sunk capital constraints in the diffusion of advanced materials, the latter are currently creating new uses rather than displacing traditional materials from existing applications. Hence the diffusion and substitution process is likely to be prolonged and uncertain as to outcome. The fact remains that such materials are critical in high technology sectors, they will become even more important in the future, and a massive research effort is underway to resolve the processing constraint. Hence there is no room for complacency in developing regions, especially given the large gains of early entry in production and use.

Some indication of the relative importance of advanced materials in comparison to traditional materials is provided in the table 3 below for the case of Japan:

Table 3 - Advanced and Conventional Material Production in Japan

	1983 $ million	1990 Forecasts $ million	Growth 1983-90 (%)
Advanced Materials			
Fine Ceramics	1,670	6.315	19
New Polymers	1,800	4,210	13
(Engineering Plastics)	1,100	2.736	14
New Metals	710	2.315	18
(Amorphous Metals)	12	147	42
Composites	105	631	29
(Carbon Fibres)	63	160	14
Total	4,285	13.471	18
Conventional Materials			
Steel	67.676	80.000	2
Non-ferrous	29,200	35.790	3
Ceramics	36.324	44,210	3
Chemicals	80.955	101,052	3
Textiles	33.945	40.000	2
Pulp and Paper	29.730	34.526	2
Total	277.830	335.578	3
Advanced Materials as % of conventional materials	1.5	4.0	

Source: Dubarle (1989): "Advanced Materials: The Silent Revolution". OECD Observer, 158, June-July, p. 9.

4. THE MATERIALS REVOLUTION AND DEVELOPING ECONOMIES.

4.1 Multi-disciplinary, transmaterial and transectoral implications

4.1.1 The emerging materials scientific and engineering foundation and consequences for developing economies.

Introduction: Some Aspects of the Transition to Materials Economies.

The analysis offered in Sections 2.1 and 2.2 above has highlighted the radical nature of the transition currently underway in the materials producing basic industries and user industries in manufacturing. There are several aspects to this transition, which necessitate that materials issues be viewed in a multi-, or at least inter-, disciplinary, and transmaterial context.

Aproaching materials research and development armed with a deep understanding of the linkages between the structure and composition, properties, synthesis and processing and performance of a material, highlights a common scientific and engineering base across the materials spectrum. The trend in modern science towards an examination of elementary particles, atoms, and molecules cuts across materials whatever their origin, and indeed crosses over and embraces other fields such as biotechnologies and genetic engineering of living organisms.

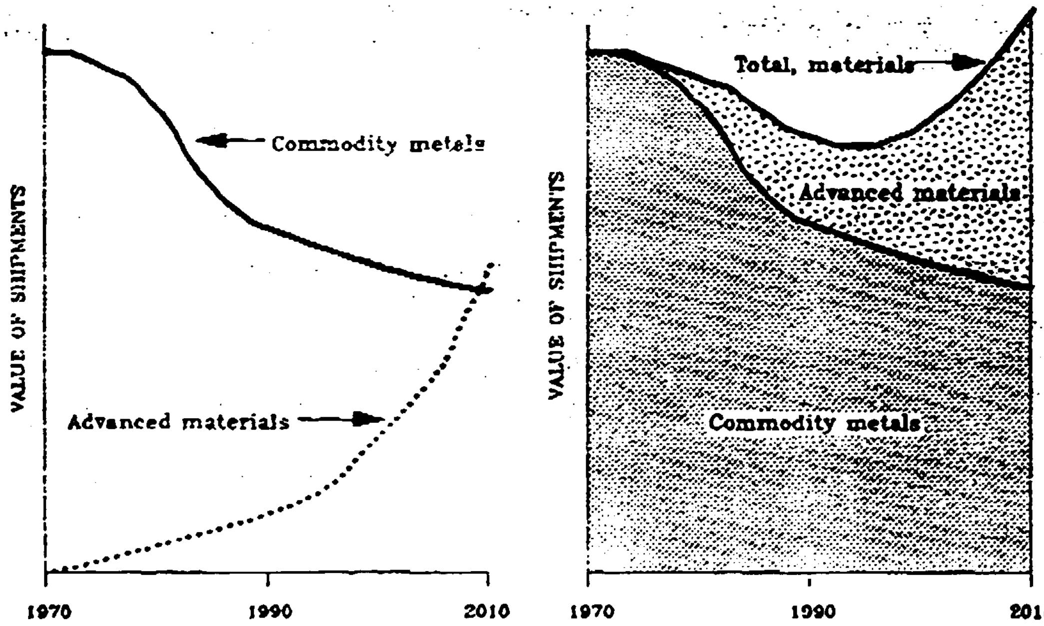
The scientific base is closely integrated to the engineering and processing stage, and the complexity of the issues requires the cooperative involvement of a multitude of disciplines and specialised individuals and research teams within and between scientific and engineering disciplines. Although traditional delineations between disciplines are beginning to erode, specialisation still occurs, so that, at the very least, cooperation across disciplines and individuals is required at this stage, before a fully-fledged multi-disciplinary competence emerges. MSE departments are beginning to train a new generation of materials scientists and engineers across the various fields of science and materials, but several years will elapse before current practices are superseded. Nevertheless, what is clear is that new materials development involves multi-disciplinary competences and synergies across diverse fields.

The multi-disciplinary scientific and engineering base is not the only mechanism that links materials and industrial sectors, indicating that a coherent and integrated approach be taken. Materials scientists and industries are increasingly becoming aware that they are in the business of designing and producing specific combinations or groups of properties and performances characteristics in use, rather than specific 'metals' or 'plastics', for example. The most astute firms are therefore in the process of transforming themselves from being, say, a specialised aluminium company to a corporation with multi-materials competences. Materials producers need to become acquainted with the design and production of several materials and with the specifications and property requirements of their customers in end-uses. Viewing this from the angle of the materials users, it means that the latter increasingly need to be acquainted with scientific and processing aspect of new materials development and use, the variety of materials available and the potential for developing materials tailor-made for new product designs. Hence issues here are beginning to acquire both a transmaterial and transectoral nature, both within and between producing and using sectors.

Throughout the 1970's and 1980's we have been witnessing a slow transition of IAC's from being primarily metals based economies toward 'materials economies'. Basic industries are restructuring such that industries and firms specialising in monolithic materials and relatively undifferentiated product structure, are giving way to multi-material firms with a large range of differentiated, high-value added, knowledge intensive products. Boundaries between traditional materials in terms of relatively well defined and 'safe' markets are eroding, with significant interpenetration of materials across uses. This is another way of viewing the fact that traditional monolithic materials have seized to constrain and dictate the design of end-use products, a profound change in the functioning, innovative capacity and growth of manufacturing industry. Materials uses are thereby being liberated from the constraints of a single or a range of traditional materials available to designers 'off the shelf'. Greater materials variety is coupled with the potential to engineer materials tailor made for new designs.

A visual guide to the nature of the transition of industrialised economies from a primarily commodity metals base towards the increasing diffusion of advanced materials in the content of the restructuring we have been describing above is shown in Diagram 4:

SUMMARY: TRANSITIONING FROM A METALS ECONOMY TO A MATERIALS ECONOMY



Source: L.J. Souse, U.S. Bureau of Mines, 1988, op.cit.

Clearly commodity metals are still expected to play a significant role in the economy over the next two decades, albeit with the ever increasing quality and knowledge-content. But beyond this, what this transition indicates is that an all-embracing, comprehensive view is required right across the materials field if we are to understand the complex nature of the issues and identify the trends. Thus, what is becoming clear is that concentration on a specific material or industrial sector is likely to miss critical aspects and trends which permeate the whole of the materials base and govern its movement and that of its constituent parts. Mono-material and specialised approaches and institutions are a dangerous anachronism in the current transition in the materials field.

The acquisition of multi-disciplinary competences and the examination of issues and trends along a transmaterial and transectoral spectrum are therefore becoming a necessity at the level of the firm, the industry and the institutions of the economy at large. This is especially the case for the private and public materials related institutions, research centres, universities and industry in developing countries in the emerging new materials era. Coming to terms with these needs will require both institutional cooperation between developing countries and between developing countries and institutions and industry in IAC's. In addition, the creation of new regional and international centres for materials basic research and techno-economic analysis, which embrace the necessary multi-disciplinary and transmaterial approach would offer significant assistance to developing economies in this complex and difficult conjuncture.

New and Improved Materials and Developing Economies

Although the radical developments in the materials field are well recognised in the scientific community, awareness of the seriousness and speed of change in this area has still not permeated the public domain. Governments[7] in the developed countries have responded to pressure from scientific and professional societies as well as high-technology sectors and have, for several years now, initiated large programmes of financial and institutional support for domestic materials pure and applied research. On the other hand, apart from few notable exceptions, both government and industry in the developing world show distinct lack of awareness of the potential impact of the new developments for domestic resources, industry and trade prospects. And, where the new scientific and technological circumstances have been identified, there is often a lack of appropriate institutional capacity to respond, and/or a feeling that such changes are too remote and operating at the frontiers of science, and, hence of not much relevance to developing economies.

It is important to stress at the outset that the revolution in materials science and engineering has an impact right across the materials spectrum, from commodity metals such as primary aluminium and copper and the creation of new advanced alloys, engineering plastics, advanced ceramics and composite systems, to agricultural commodities such natural fibres and, others such as natural rubber, wood, cotton, and cement. New advanced materials are beginning to make inroads into the markets of traditional materials, such as monolithic metals, but the latter are actually responding scientifically, technologically and in terms of marketing strategies, so that the outcome is by no means clear. In fact, advanced materials in the next century could well include specialty steels, advanced aluminium alloys, and in some respects, higher quality cement and wood.

A number of propositions follow and we briefly discuss them below:

1. Improve traditional materials and processing technologies.

   The first important point to note is that the insights of materials science and engineering as set out in 2.1 above, can be used and must be used to improve the properties and processing technologies of existing traditional materials.

   Tremendous scope exists for the 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. (See also section 4.1.2 below).

   Further, given the pressures of the world market and user -industries (see 2.2) for higher quality, durability, and reliability no industry or economy can afford to ignore this, at any stage of the materials cycle. This applies

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[7] International Cooperation and Competition in Materials Science and Engineering, National Institute of Standards and Technology, U.S. Department of Commerce, June, 1989.

to materials selection in a range of user manufacturing activities, from designer dominated, small-scale, flexibly specialised industries such as clothing, furniture and footwear to the provision of materials, components and sub-assemblies to the emerging flexible mass production industries such as automobiles. The decision to locate in, or, source from developing economies in the 1990's will be greatly affected by the quality and reliability of the materials on offer.

Further, the successful efforts to improve the properties of commodities such as natural rubber, wool and cotton as compared to synthetics is a pointer to greater collaborative efforts by LDC's on a regional, and cross-commodity basis.

2. A Materials Science for Development.

The large and increasing basic needs of developing economies in housing, transportation, food packaging, water and energy distribution and health care can be met[8] through more efficient utilisation and upgrading of domestically or regionally available natural resources, using scientific in sight and new and improved technologies. The materials revolution affords opportunities to developing economies to make fuller use of domestic materials, while minimising energy requirements and environmental disruption. Included in this is the development of advanced MATERIALS designed to meet needs and conditions in developing countries.

We concur with Professor Rohatgi, that the new materials science and engineering base must be mobilised, internationally and within the Third World, to meet the needs of development in the coming decades. For although the science base of the new materials is common throughout the world, the direction of application and problem orientated 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 is given in Table 4 . In so far as possible such materials should be "...small, lighter, longer lasting, low cost, low energy and recyclable based on abundant and renewable resources which can be locally processed using simple and employment generating non-polluting technologies".

In housing, MSE can examine alumino 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 be used to extract 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 for the production, transportation and storage of food. It is worth noting that the U.S. based Alcoa corporation is currently researching into new advanced packaging materials for food and post-harvest products,of great relevance to developing economies.

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[8] Professor Pradeep Rohatgi, Current Revolution in New MATERIALS: Opportunities for the Developing World, Regional Workshop on Advanced Materials Technology and Development in Asia and the Pacific, Minsk, USSR, 29 May - 2 June, 1989.

Table 4: Some Important Targets for Materials Technology for Development

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- Genetic engineering for plants to get nitrogen directly from air.
- Genetic engineering for plants with stronger timber and fibers which can be pyrolized to form high performance fibers and carbon-carbon composites.
- Microbial processes to extract metals from ores and ocean nodules, and to remove sulphur and silica from coal, bauxite and other minerals.
- Microbial processes to extract fibers and ultrafine ceramic particles from agricultural products and wastes.
- Solar photovoltaic materials with increasing efficiencies and decreasing costs; solar furnaces for processing materials.
- Materials for fusion energy.
- Membranes made for polymers, ceramics and composites with decreasing costs and increasing performances for purification of water.
- Improved and inexpensive materials for housing from abundant and renewable resources like sand, clay, rock, stones, laterites, plant based materials.
- Composites and ceramics with improved performances based on abundant elements like Al, Si, C, N and plant materials.
- Direct Reduction of iron and aluminum using low energy processes, using solar and biomass energy.
- Recyclable materials with cascading downgraded application with longer life and resistance to corrosion, oxidation, wear and fatigue.
- Rapidly solidified materials for reducing energy losses.
- Surface and interface processed materials with tailored structures and properties to meet specific needs.
- High performance nano-structured materials, nonequilibrium and metastable structures.
- Room temperature superconductors.
- Insitu polymer composites.
- Tough ceramics.
- Net shaped materials fabrication.
- Parts consolidation through single step molding of complex shapes.

Source: P. Rohatgi, 1989, <u>op. cit.</u>

3. Raw Materials for Advanced Materials.

Many developing economies possess materials and/or technology 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, qualify control and trade at several stages of the transformation of the raw material into semi-processed and processed forms and components entering final use.

Consider, as an example, the rare earth element neodymium[9] and its use in the new generation of permanent magnets. Neodynium 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 existing practical permanent magnets is provided by the rare earth cobalt magnets. Nevertheless there are indications that the new generation of supermagnetic materials, which have generated large international interest, 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 Xenotime and constitutes about 17%, by weight, of all rare earths mined. The main producers of rare earth minerals are to be found in the U.S.A., Australia, China, India, Malaysia, U.S.S.R., Brazil, Canada, Sri Lanka, Thailand, Zaire and Medagascar, in order of importance. Neodymium constitutes about 13% of rare earth content, and the distribution of its reserves is shown in Table 5, indicating a 100 year life.

Table 5: Neodymium Reserves in the World

Country	Estimated Reseserves Kg x 103
USA	650,000
India	400,000
South Africa	15,000
Central Africa	6,000
Malaysia	5,000
Brazil	5,000
China	4,600,00
USSR	70,000
Australia	8,000
Others	50,000

Source: N.C. Kothari, 1989.

Taking advantage of the opportunities offered by neodymium in magnetic, colour glass, capacitors, and laser applications and of other rare earth elements in magnetic property applications and in advanced ceramic and glass technologies will doubtless involve familiarisation 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,

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[9] N.C. Kothari 'Neodymium Supermagnet - Key Material for Tomorrow's Electrical and Electronic Industry'; Minsk Workshop, 29 May - 2 May, 1989, ibid.

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.

4. Materials and the Environment.

Finally, it is important that improved and new advanced materials extraction, processing, application and recovery address the issues of environmental degradation and health hazards. These issues are no less significant and relevant in developing countries than they are in IAC's.

While, on the one hand, materials production and use is inextricably being linked to environment concerns and hence, increasingly, to environmental and safety regulations, the materials revolution offers, on the other hand, scope for developing materials and technologies that can act so as to reduce or eliminate pressures on the environment.

In the production[10] of materials, pollution can be generated by solvents during a curing cycle, or health risks may be present due to particle dispersion of ultra-short fibres in ceramics or composite fabrication, or the inhalation of fumes in reinforced plastics. In the use of materials environment and health may again suffer and must therefore be controlled. A neglected but very important area refers to pollution generation by tarred surfaces (e.g. roads, car parks, airports, roofs etc.). Tar is essentially the rubbish damp of the petrochemicals industry, containing 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 pouch with controlled surface properties. This would give a large impetus to polymer producers, public works companies and the oil companies enabling them to eliminate residual tar and using 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 destroying the materials. They are non-neutral to the environment, in the sense that they do not decompose and may be harmful in the long-run. Fibre-composites cannot be discarded after use and technologies do not exist to reuse the matrix fibre. And scrapped cars, washing-machines etc are increasingly less attractive for recovery and move difficult to separate.

The major areas of concern in the 90's 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 public utilities in the 1990's. 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 reliability and safety of components and final products.

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[10] P. Cohendet et.al., New Advanced Materials, Springer-Verlag, 1988.

Developing economies need to participate in the efforts to harmonise regulatory policy on environment. ., materials and health across IAC's, and the efforts to regulate production 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.

4.1.2 The crucial importance of enhanced competence in materials synthesis, processing and engineering.

Synthesis and processing as a unified series of activities by which new arrangements of atoms and molecules are transformed cost-effectively into materials and components refers to a wide range of activities, such as the rolling of aluminium and copper, the pressing and sintering of ceramic powders, thermomechanical processing of alloys, surface coating of metals, growth of gallium arsenide crystals, laying-up of composite MATERIALS, sol-gel production of pure ceramic powders and so on. Such techniques are essential for supplying industry with low-cost materials with requisite properties and performance characteristics. And, synthesis and processing capabilities are the essential mechanism by which new scientific and technological insights are transmitted into the production system in the form of useful materials and components.

The possession, acquisition and continuous development of synthesis and processing pure and applied research capabilities and technologies is a critical determinant of competitive advantage for low-cost production in traditional materials industries and in the development and application of new materials. In fact, tremendous potential exists in the development of existing and long-standing processing technologies in traditional materials industries.

It is likely that a major component of commodity, industry and trade strategies in the 1990's would be the need for developing economies to strengthen engineering capabilities in the area of materials processing and fabrication technologies. The prudent and selective acquisition and strengthening of existing skills in processing and engineering technologies, coupled with the necessary educational, vocational training and infrastructural policies, would provide several developing economies with an effective mechanism with which to access new scientific developments, and a stepping stone towards the transformation of the industrial base while utilising the insights of MSE to meet domestic basic needs and a means for cost effective participation in the world market in traditional and, where appropriate, new materials. No economy can become involved in all materials, and specialisation therefore would be necessary. The acquisition of purely scientific capabilities per se is wasteful and possibly irrelevant for many developing economies.

4.1.3 Information, standards and quality assurance

The rapid proliferation of new and improved materials has highlighted the inadequacy of current definitions and standard classification schemes in terms of capturing the statistical importance of the phenomenon of advanced materials. At the same time it is becoming clear that access to up-to-date and comprehensive empirical information is vital to both industry and government in assessing the economic significance of advanced materials in terms of production, use, diffusion in specific sectors and displacement of traditional materials.

Access to information and data on materials properties and associated testing conditions, availability, producing companies, and quality assurance are emerging as a central determinant of global competitive advantage. It is important that LDC industry, universities, and other institutions not be excluded from such information. Hence, concerted effects must be made nationally, regionally and internationally to facilitate developing country on line access to materials data banks being developed currently in the IAC's, and participation in the efforts to harmonise the building of data bases across national economies, as is currently underway in the E.E.C. On the other hand, it is, and will become even more important that a comprehensive inventory and data base of LDC's materials availability, properties, testing procedures and specifications, be built up over the next few years, since this is a primary consideration to industry in IAC's and other LDC's in terms of decisions to import and source materials and components or invest in plant utilising local materials.

A basic problem in building and accessing materials data base concerns standards and testing procedures employed across different industries, let alone countries. Very often there is a lack of compatibility in the properties and designation of engineering materials and the testing procedures under which they were obtained, as well as at the level of software, user interface, data presentation, terminology and data bank commands. The importance of upgrading or creating national and regional standards and testing institutes, the raising of awareness across industry of the need for quality assurance, and harmonisation of testing and specifications, and the coupling of this with the ongoing harmonisation of standards throughout IAC's must be a priority to LDC's, at all stages of development, in the new materials era of the 90's. This will play a significant role in international trade, foreign direct investment and transfer of technology in the years to come.

4.1.4 Access to foreign technology and the role of MNC's

The aim must be to assist the development of domestic technological capacity and skills in a dynamic context. In this, training abroad, the acquisition of foreign technology and regional collaboration in research, training, standards and education would play a central role. Depending on the level of development of the productive forces some economies, such as Brazil, South Korea and Singapore may need and have opportunity to enter into joint ventures directly with companies engaged in advanced materials production in IAC's. Other countries may more usefully build upon their existing technological and traditional materials strengths by entering into collaborative agreements with firms and institutions in other developing countries in their region. Even though large corporations dominate in bulk materials another feature of the materials revolution is the importance of the small company accounting for the evidence of flexible specialisation and production for small market segments, too small for the larger companies. Countries need to closely examine the potential benefits of engaging in joint ventures and licensing agreement with either large MNC's or smaller specialised firms from IAC's in areas related to their existing resources and strengths. Such agreements could assist the efforts for forward integration and diversification of the export sector, enhance the skills, scientific capacity and managerial and technological know-how in a range of primary and manufacturing sectors, assist the penetration of foreign markets, enable the economy to accumulate experience in the use of new materials, and, where possible, facilitate the transition to advanced material production. For example, as part of a national scientific and industrial strategy, domestic traditional glassware and ceramic producers could be assisted to move to advanced ceramics production in the long run, with a prudent combination of enhanced domestic skills and acquisition of foreign technology. There are important lessons here from the evolution of the Japanese and South Korean ceramics industries in the 70's/80's. In the space of a few years South Korea has emerged as a major force in electronic ceramics, while its universities pour out ceramics graduate and doctoral students every year.

4.1.5 Institutions and Government

The effectiveness of the organisational setting of government and institutions needs to be strengthened if economies are to come to grips with the complexities and practical implications of the materials revolution. An important requirement would be the creation of a central think-tank or council employing an interdisciplinary engineering and scientific team with the ability to monitor scientific and technological developments, analyse them and translate them into concrete industrial, educational and training domestic policies. Good examples here are the Secretariat on Advanced Materials in the Brazilian Ministry of Science and Technology, which comes directly under the Office of the President, and the Nucleus for the Study and Planning on Advanced Materials in the Brazilian Institute of Science and Technology, which is probably the first multi-disciplinary group to study advanced materials in a developing economy. Such a council should have the power to horizontally coordinate various government departments, monitor progress and implementation, and coordinate materials research in private industry, universities, research institutes and laboratories and government. All LDC's economies need to address the need for creating the appropriate institutions and mechanisms to effectively manage and respond to rapid change in the 1990s.

4.1.6 Human Resource Development.

In the age of advanced materials, highly qualified professionals will be as much in need as the acquisition of middle level skills and technicians for the unpackaging and use of new technology. Development economies must give the highest priority to the acquisition of skills at all levels through increased domestic education expenditures and training programmes, the training of nationals abroad, cooperative programmes across Africa, Asia and Latin America and participation in international scientific societies, consortia and trade associations. Greater emphasis must be given to pure scientific training and research and mechanisms must be sought for greater linkages between the conduct of R&D and its channelling towards commercial application in industry. The skills, competence and priorities of the banking sector is an area of crucial interest here, in mobilising financial resources for materials ventures and training and educational programmes. A feature of the new era is that scientists, engineers and managers must be constantly updated and retrained.

4.2 Opportunities and needs for techno-economic and institutional cooperation.

4.2.1 Regional and international cooperation

Of recent, the implications of new materials for economic development have began[11] to receive attention in a number of regional and international meetings. A common theme that emerges is the strong need for regional and international cooperation and networking by developing countries institutions in the areas of materials information and data gathering, testing and standards, professional societies, experimental and laboratory facilities, and cooperation in research and development efforts across universities and industrial laboratories.

UNIDO has, appropriately and commendably, been especially active in this area. Apart from holding high level meetings on advanced materials, it is exploring possibilities for the establishment of regional centres of excellence and networking of standards and testing institutes across developing regions. In addition[12] it is in the definition stage of the establishment of a new international

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[11] See Report of the Regional Workshop on Advanced Materials Technology and Development in Asia and the Pacific, Minsk (USSR), 29th May - 2 June 1989. International Symposium on Advanced Materials in Developing Countries, World Materials Congress 24-30 September 1988, Chicago, USA. Final Report, Expert Group Meeting, UNIDO, Vienna, April 4-7, 1989, and Report, Discussion Meeting on Advanced Materials for Developing Countries, op.cit, UNIDO, Vienna, 7-10 December 1987.

[12] See L. Kaounides: "The establishment of an International Materials Assessment and Applications centre (IMAAC). A document by an expert mission on the design and definition phase of the project, 8th October-17 November 1989". UNIDO, December 1989, pp 44.

centre in Brazil, the purpose of which would be to provide centralised information and data services and engage in studies of a techno-economic nature addressing the transectoral complex and multi-disciplinary materials issues of relevance to developing economies in the 90's and beyond, in the framework of international cooperation. A complementary activity relates to the establishment of an International Centre for High Technology and New Materials in Trieste, Italy, which will engage in experimental and scientific work on semiconductors, superconductors and composites.

4.2.2 South-South trade in an open and dynamic world economy.

In addition, there is clearly an important role here for South-South trade as production capacity and infrastructural requirements expand in countries at different levels of development. It is interesting to note the changing direction of developing country primary commodity exports in recent years, as Table 6, shows:

Table 6: Changing destination of exports of primary commodities from developing countries

(Percentage share of intra-developing country exports in total developing country exports)

	1973	1980	1986
Food	17.9	23.5	19.9
Raw materials	22.7	26.1	27.7
Ores and minerals	6.7	11.5	18.2
Non-ferrous metals	11.0	15.7	22.7
Fuel	18.6	22.2	27.9
Total primary products	18.0	22.1	24.9
Excluding food and fuel	16.0	19.3	23.6

Source: World Economic Survey, 1989, UN, ST/ESQ/211.

As industry has been growing in the more industrialised LDCs, this has provided expanding markets for primary exports from other LDCs. Most of the increase has been due to imports by Asian LDCs. In fact, exports of primary non-fuel commodities from Asian economies to other Asian economies as a percentage of their total exports went up from 22.5 per cent during 1966-70 to 34 per cent during 1983-85, while exports from African and Latin American LDCs to other LDCs also registered large increases in the same period. There may well be further scope for South-South primary trade, especially if trade barriers come down. But it must be remembered that the industrialisation process, especially in the first tier NICs, will also be accompanied by the application of sophisticated manufacturing technologies, and this will have repercussions on the type and quality of materials, including advanced materials, required.

The 42 least developed economies (UNCTAD, Trade and Development Report 1989), comprise of a population of 340 million, and are distinguished from other developing economies, because of even lower levels of per capita income, lower levels of adult literacy, smaller share of manufacturing in total GDP, lower savings and investment rates, very large percentage of labour in primary, mainly subsistence sector, and high export concentration on few, mainly primary, commodities (65% of total export earnings in 1986). At the same time they suffer from a very weak infrastructure with poor networks of communication and transport.

During the 1980's they experienced enormous cutbacks in education and teacher training programmes, while investment to maintain a deteriorating industrial and infrastructural base has been lacking. These economies have effectively been marginalised in the world economy, with their combined world export market share in 1987 being a quarter of its value two decades earlier, while the share of other developing countries remained constant during this period. Their export markets are heavily concentrated, mainly to the EEC, while their markets in other developing countries are generally low. Clearly, the changing materials and manufacturing conditions in the world economy pose a real threat to further marginalisation of these economies in the 1990's, unless action is taken now to upgrade their educational, training, engineering, standards and quality control, and institutional capabilities consistent with existing resources and strength. South-south trade and regional collaboration in R&D, training, information and data, and standards institutes networking would play an important role in the effort to target and selectively acquire dynamic comparative advantage opportunities. It must be noted that several of these economies, especially in sub-Saharan Africa are actually rich in resources.

If we now look at the NIC's, and the four in south-east Asia in particular, we see that their industrial structures are moving towards high-value added, sophisticated products and are finding themselves in need to enter into joint ventures of conclude licensing agreements with foreign companies in order to upgrade their technological capabilities. While wages have been rising in these economies, domestic firms have been looking to neighbouring economies for cheap labour and foreign firms, especially Japanese, are either relocating labour intensive activities from Taiwan and South Korea to other economies or have been avoiding these relatively high wage economies altogether in recent years. On the other hand, higher wages, a developed infrastructure and higher workforce skills, have altered the attractiveness of the four economies to foreign firms. Foreign direct investment now flows in highly skilled, sophisticated activities, while higher wages imply larger markets encouraging the inflow of foreign firms. Moreover, foreign firms now locate there to produce sophisticated components and advanced materials for domestic use or re-export to Japanese industries.

Therefore, there is a dynamic process under way in est Asia whereby the move to higher-value added industrial activities by the rapidly industrialising NIC's, has created vacancies or opportunities to other countries in the region to enter into relatively more labour intensive industries and segments of the production process. Lower wage economies such as Thailand, Malaysia, the Philippines and Indonesia can thereby expand their industrial base and expertise by building on existing strengths and competitive advantages, without neglecting the need to build their educational, scientific and technology skills. These second tier economies also possess considerable natural resources entering world trade, in comparison to the four first tier NIC's mentioned above. On the other hand they have serious infrastructural constraints, as in the unreliability of the electricity system.

5. CONCLUSIONS

In this paper, we first identified the central characteristics and trends of the revolution in MSE, in section 2. We then integrated these elements with the restructuring process underway in IAC's since the early 1970's, under the auspices of the production and generalised application of information technologies. We point to the fact that great changes are occurring at the early stages of production, leading to a transformation of the traditional metals and chemicals input industries into materials producing branches permeated by the insights, practices and philosophy of the evolving MSE. Further, we pinpoint the inseparable links which have emerged between the design, processing and use of new materials and the changing needs of market demand, consumer tastes, and associated flexible production technologies, as IAC's undergo a slow and uneven transition towards impact on demand for traditional industrial raw materials, the global resource base, corporate strategies and global location patterns, as well as the necessary large role played by the state in IAC's in promoting national competence in materials production and use, deemed necessary for current and future domestic competitiveness. We then crystalise the insights obtained from these sections into a brief outline of the potential impact and the implications for developing economies in the 1990's and beyond (section 4), and identify those policy areas that such economies must begin to offer strategic responses to.

The diffusion of microelectronics and telecommunications and, increasingly, of new materials technologies is clearly having an impact throughout manufacturing in both large-scale and small-scale industries and in traditional, labour intensive as well as newer, technologically progressive activities. What is, therefore, the Third World to produce in the 1990's, with what technologies and materials, at what scale, and where? Clearly some economies would do well concentrating on small scale, flexible specialisation type of industrial activities aimed at niche markets in specific designer dominated sectors. But this cannot be the case for all developing economies. Others, such as the NIC's and second tier NIC's, could and would profitably engage in high-value added, knowledge intensive production, including diversification into advanced materials. But where does that leave the majority of LDC's, indeed, the low-income LDC's? There is therefore an urgent need for an identification of the appropriate scientific, technological and institutional responses required across the whole spectrum of LDC's, such that such economies can negotiate and survive the major discontinuities ushered in by the information and materials revolution.

Commodity policy must at last move away from an obsessive concentration on market prices and redistribution and concentrate on the need for primary producers in sub-Saharan Africa, the least developed economies, lower-middle income and second-tier NIC's to build and acquire the necessary competences in MSE and parallel educational, engineering, testing and quality control, standards and institutional skills and structures that will enable them to use domestic resources to meet basic needs and participate in the world economy. For a primary objective of international economic policy in the 1990's, must be avoidance of the further marginalisation of that large number of economies which least afford to be cut off from the fruits of the materials information and biotechnology revolutions and from world economic activity, trade and payments.

Therefore, the issues that would loom large in policy discussions in the 90's will include the following: Institutions which can acquire, assimilate and use materials data and information; testing and standards institutes; processing and engineering capabilities as a central concern of industrial strategy giving access to MSE insights and research, and ability to transmit them to commercial application; the concerted effort by universities, government and industry regionally and internationally to divert the vast potential offered by MSE to meet basic needs utilising local resources while meeting environmental and energy constraints; and, technical cooperation between professional societies, universities, institutes, research centres and industry in developing countries on a regional and international basis to meet the challenges posed by new materials and the environment.

In this, of central concern will be the point of entry and selectivity in building up scientific and materials and manufacturing engineering skills, utilising existing strengths while entering into joint ventures and technology licensing agreements, in the context of a dynamic and coherent industrial strategy, in which governments will play a role in setting priorities in a targeted approach. There are many opportunities for developing economies to enter into various stages of the materials and manufacturing cycles while judiciously building on existing strengths in domestic materials, manufacturing technology and human skills.

APPENDIX

Advanced materials classes, chemical composition, processing path, properties and functional use

I. Metals

II. Structural Ceramics

III. Engineering Polymers

IV. Functional Devices: Electronics, Optical and Magnetic

V. Medical and Dental Materials

Source: Office of Advanced Materials Coordination, U.S. Bureau of Mines, Open File Report, OFR 4887, December 1987.

I. METALS

MATERIALS CLASS	CHEMISTRY AND FORM	PROCESSING METHODS	CRITICAL PROPERTIES	USES OR POTENTIAL USE
A. Structural.				
Superalloys	Co - based Ni - based with Cr, Mo, Cb Ta, W, Hf, Zr	Investment cast as polycrystalline, directionally solidified, or single crystal.	High strength at high temperatures; Corrosion resistance.	Jet engine components resistance wire.
Aluminum - Lithium Alloys	Al-Cu and Al-Mg with 1-3% Li	Conventional	Low density; high stiffness.	Aircraft skin and structure.
Amorphous Alloys	Fe - based Co - based with Al	Rapidly cooled	High hardness and tensile strength; corrosion resistance; high magnetic permeability, free of anisotropy; high electrical resistance.	Reinforcement for composites; corrosion resistance materials; magnetic applications
Rapidly Solidified Alloys	Al-Si; Many alloy systems	Very rapidly cooled as powders, ribbons.	Solid solubility increased; all properties altered.	High strength powder metallurgy products.
Superfine Particles	Many alloy systems	Liquid metal atomized to form submicron particles.	Large surface areas; paramagnetic; high reactivity; high sinterability.	Catalyst carriers; filters; sintering aids; fillers.
Ordered Intermetallics	Ni Al; Cu-Al-X alloys (X=Fe, Ni, Mn, Be, Co, Si, Sn)	Conventional, with annealing to obtain correct phase content and microstructure.	Resistance to corrosion and corrosion fatigue; High strength in heat-treated forms.	Structural materials with hot corrosion resistance; Jet engine components; ship construction.

I. METALS

MATERIALS CLASS	CHEMISTRY AND FORM	PROCESSING METHODS	CRITICAL PROPERTIES	USES OR POTENTIAL USE
Shape Memory Alloys	Cu-Zn-X (X=Si, Sn, Al, Ga); Cu-Zn; Cu-Al-Ni; Cu-Sn; Cu-Au-Zn; Ni-Al; Ti-Ni; others.	Conventional; shaped below transition temperature.	Regains original shape when heated above transition temperature.	Pipe clamps, sensors and actuators; orthodontic wire; eyeglass frames; specialty rivets; kinetic energy storage.
Copper-Beryllium Alloys	Cu-Be	Conventional	High strength increases with temperature; high fatigue resistance; high thermal conductivity.	Precision current-carrying springs; electrical connections test probes; components for robots.
Surface Hardened and Coated Metals	Carbides, nitrides, and borides of B, Cr, Hf, Mo, Cb, Si, Ta, Ti, V, W, Zr. Zirconia and mullite coatings.	CVD; PVD; thermal spray; plasma spray.	Corrosion, wear, and heat resistance.	Many structural applications.
Titanium Alloys	6% Al, 4% V, etc.	Conventional	Low density, high strength at medium temperatures, toughness, corrosion resistant.	Airframes, skin, turbine parts.
Superplastic Alloys	Ti alloys Superalloys	Fine grains for superplasticity, followed by heat treatment for strength.	Fewer machining and finishing steps.	Aircraft structure and engine components

I. METALS

MATERIALS CLASS	CHEMISTRY AND FORM	PROCESSING METHODS	CRITICAL PROPERTIES	USES OR POTENTIAL USE
B. Absorptive.				
Hydrogen Storage Alloys	Li, Mg, Y, V, Cb, Pd, U, Fe Ti, $LaNi_5$.	Conventional	Retain more H than tanks at moderate pressure; absorption and release reversible with temperature change.	Stationary or mobile storage; heat engines; water splitting; H-isotope separation; fusion reactor technology.
Porosity Metals	Alloys of Ni, Cr, Cu, Al, Ag, Zn, Pb.	Foamed during solidification.	Up to 98 pct. pore volume; continuous pores.	Electrode plates; catalyst carriers; filters.
C. Composites.				
	Matrices of Al, Cu, Zn, Ti, Ni, Reinforcements of Al_2O_3 , mullite, B, and SiC fibers; SiC whiskers; Al_2O_3, SiC, Si_3N_4 particulates.	Prepreg lay up for continuous fibers; casting or CVD of matrix.	High strength and fracture toughness; low densities.	Aircraft, automotive, ship structural components; machinery, space structures.

II. STRUCTURAL CERAMICS

MATERIALS CLASS	CHEMISTRY AND FORM	PROCESSING METHODS	CRITICAL PROPERTIES	USES OR POTENTIAL USE
D. Monolithic.				
Oxides	Al_2O_3; partially stabilized ZrO_2 (PSZ); tetragonal zirconia polycrystal (TZP); BeO; cordierite; SiO ; mullite; Al_2TiO_5; Y_2O_3; ThO_2.	Prepared as submicron powders; formed by pressing; sintered at high temperatures with or without pressure.	Heat resistance; strength; wear resistant; corrosion resistant.	Turbine blades; adiabatic engine components; heat exchangers; cutting tools; bearings; catalyst carriers; mechanical seals; nozzles; RF crucibles; nuclear shielding.
Non-oxides	SiC, Si_3N_4, SIALONS, B_4C, AlN, hexagonal BN, cubic BN, TiB_2, ZrB_2, TiN, TiC.	Prepared as submicron powders; formed by cold or hot pressing, with or without sintering aids; sintered at high temperatures, with or without pressure.	Heat resistance; oxidation resistance; strength at.	
B. Composites.				
	Matrices of oxides and non-oxides; reinforcements of C, SiC, Si_3N_4, Al_2O_3, aluminosilicate fibers; SiC whiskers; PSZ particulates.	Processing not yet developed; fiber prepregs treated with slurry.	Heat resistance; improved fracture toughness; "graceful" fracture.	All the applications of monolithic ceramics.
	Carbon matrix/carbon fiber composites.	Continuous fiber prepregs; CVD carbon matrix.	Heat resistance; strength; low density; (needs protection from oxidation).	National Aerospace Plane skin; rockets and missiles; space structures.

III. ENGINEERING POLYMERS

MATERIALS CLASS	CHEMISTRY AND FORM	PROCESSING METHODS	CRITICAL PROPERTIES	USES OR POTENTIAL USE
F. <u>Structural</u>.				
	Polybutylene terephthalate (PBT) Polyethylene terephthalate (PET) Poly (4,4' isopropylidine diphenylene carbonate (Polycargonate) Polyether sulfone Polyarylate Polyphenylene sulfide (PPS) Polyamide-imide Polyetherether ketone (PEEK) Poly (Paraphenylene benzobisimidazole) (PBI) Poly (Paraphenylene benzobisoxazole) (PBO) Poly (Paraphenylene benzobisthiazole) (PBT) Liquid crystal polymers Polymer blends	Chemical reactions of resins with reagents at elevated temperatures; blow molded; injection molded; sheets; films; pultruded.	Melting temperatures between 240 C and 530 C; high strength and stiffness; low densities.	Structural materials for aircraft, automobiles, office equipment; electromagnetic interference shieldings.
G. <u>Composites</u>.				
	Matrices any of the thermoset resins or thermoplastics; reinforcement of glass fibers, boron fibers, carbon fibers, chopped fibers, whiskers	Continuous fiber prepregs laid before pouring or molding; chopped fibers, whiskers, and particulates added prior to	Very high tensile strengths and fracture toughness; low densities.	Structural materials for multitude of applications.

IV. FUNCTIONAL DEVICES

MATERIALS CLASS	CHEMISTRY AND FORM	PROCESSING METHODS	CRITICAL PROPERTIES	USES OR POTENTIAL USES
H. Electronic and Optical.				
Dielectrics	Al_2O_3, BeO, AlN, diamond film, MgO, polyimide.	Ceramic Sintering, CVD, polymer reaction.	Electrical insulation; thermal conductivity.	IC substrates, packaging.
Ferroelectrics	$BaTiO_3$, $SrTiO_3$	Ceramic sintering	Dielectric over defined voltage range.	Ceramic capacitors
Piezoelectrics and Non-linear Optical Devices. titanate (PLZT),	Quartz, lead zirconium titanate (PZT), lead lanthanum zirconium $LiNbO_3$, ZnO, polydiacetylene (PDA), liquid crystals.	Ceramic sintering, CVD, polymer monolayers, single crystal growth.	Piezoelectric or non-linear optical properties.	Vibrators oscillators, transducers, spark generators, optical switches, optical modulators.
Semiconductors	Si, GaAs, SiC, In GaAsP/InP, GaAlAs/GaAs, HgCdTe, Cd (S, Se), $ZnO-Bi_2O_3$, V_2O_5, In-Cu-Se/Zn-Cd-S.	Single crystal growth, CVD; molecular beam epitaxy.	Semiconducting over defined and controllable ranges; optical transparency for some uses.	Integrated circuits, solar cells, thermistors, sensors, varistors.
Light Emitters	GaAs, Gap, PLZT, yttrium aluminum garnet (YAG), InP.	Single crystal growth, CVD; ceramic sintering.	Electricity-tight conversion.	Laser diodes, light-emitting diodes, phosphors.

IV. FUNCTIONAL DEVICES

MATERIALS CLASS	CHEMISTRY AND FORM	PROCESSING METHODS	CRITICAL PROPERTIES	USES OR POTENTIAL USES
Optical Fibers and transparent Ceramics.	SiO_2, Al_2O_3, AlON, MgO, Y_2O_3-ThO_2, Ba-La-Zr-Al-Na-F, polymethylmethacrylate, selenide glasses.	Glass fiber pulling and chemical treatment.	Optical transparency with low loss over a range of wave lengths.	Fiber communications, IR transmitters, high pressure lamps.
Ionic Conductors	Beta-Al_2O_3, ZrO_2, ZnO, Fe_2O_3, SnO $MgCr_2O_4$-TiO_2.	Ceramic sintering.	Ion-specific conductivity	Solid electrolytes, fuel cells, humidity sensors, oxygen sensors, hydrocarbon and fluorocarbon detectors.
Superconductors	Ni-Ti, V_3Ga, Nb-Ti, Nb-Sn, $YBa_2Cu_3O_x$, type ceramics.	Metal-forming ceramic sintering, CVD thin films.	Zero resistance, magnetic field strength, current density, Josephson effect, Meissner effect.	High speed LSI, electromagnets for NMR imaging, magnetic levitation, power transmission, transformer cores.
I. <u>Magnetic.</u>				
Metallic	SrCo, powder alloys, Nd-Fe-B, superconductors.	Metal forming	Magnetic field, permanent or electromagnetic.	Magnetic heads and tapes, transformer cores, motors, NMR imaging instruments.
Ceramic	$BaFe_{12}O$, $SrFe_{12}O_{19}$, $YBa_2Cu_3O_x$ type ceramics, other ferrites.	Ceramic powders, ceramic sintering, CVD.	Magnetic field, reversible polarity.	Magnetic tapes, motors, NMR.

V. MEDICAL AND DENTAL

MATERIALS CLASS	CHEMISTRY AND FORM	PROCESSING METHODS	CRITICAL PROPERTIES	USES OR POTENTIAL USE
J. Structural.				
	Al_2O_3 structures.	Fine powders sintered at high temperatures.	Biologically inert; corrosion resistant; high strength.	Bone replacements.
	Hydroxyapatite	Formed as a glass; cast.	Biologically compatible.	Bone and teeth replacements.
	Carbon fiber/ polylactic acid composites.	Chemical formation of PLA on C fiber prepreg.	Histocompatibility; dissolves as healing occurs.	Tendon replacements.
K. Functional.				
	Silicone, fluoropolymers.	Chemical reaction; polymer forming.	Histocompatibility	Artificial blood vessels; heart repair soft tissues.
	Acrylic, methacrylic resins.	Chemical reaction; polymer forming.	Histocompatibility.	Artificial kidneys.