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The Impact of Advanced Materials on World Development

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1-Introduction

The rhythm of expansion experienced by the world-wide economy after II World War started to show signs of cooling off in the late 1960s. In the main this basic condition has forced advanced countries and institutions to move from a state in which incremental innovations, rationalization and optimization of production processes prevailed to a radically new situation where the emphasis is placed on the search for different patterns of growth and development.

The most impressive features resulting from efforts made during the subsequent decades can be summarized by the advance and progressive consolidation of the so-called high-tech areas (such as information technology, biotechnology, advanced materials); by the attempts at transforming and reorganizing the production process (with its increasing flexibility and growing scientific and knowledge content); and by the strong possibility of alterations in the international division of labour and international technological and economic leadership. Evidently all these aspects are linked and much attention has already been focused on them and on their interconnections.

The central objective of this paper is to discuss the importance of the development and introduction of advanced materials into this scenario of global transformation, their diffusion throughout the world economy and the impact they are already producing and are expected to produce on developing countries.

The advent of advanced materials, in close association with the spread of information technology, is considered capable of playing an important role in the process of industrial restructuring, affecting patterns of investment, organization, employment and trade. Developments in most sectors that are now promoting and using high technology rely and depend upon improvements in the materials front.

Many attempts have been made to define and characterize advanced materials (AMs). Given the elementary and fundamental importance of a correct understanding of this notion, the different approaches are discussed in section 2. As indicated there, one can find extremely precarious and biased the usual interpretations of the concept of AMs. Probably the main reason for this is the fact that this term has grown up in an environment of national and international policy making. It has, then, to be understood in this precise context.

It is recognized, nowadays, that a major step forward in the ways of analysing and understanding the structure and properties of matter has been achieved. This is considered a crucial aspect that set the basis for an inversion in the logic of production. A given product no longer relies on a given material nor on given inputs. Instead, several materials compete to assume a given function. In section 3 it is emphasized that these recent changes can neither be considered simply as a spontaneous and neutral movement, nor as only the result of incremental innovations. In addition to the analysis of the tendency to open up a wider availability of raw materials for the production of AMs, the importance of the information-intensive character of their production is examined. The fact that AMs can play an important role in terms of contributing to changing the present patterns of economic and technological leadership is also discussed in this section.

The revolutionary advances in materials science and technology have been produced by policies (some of which implicit) implemented mainly by governments and firms in the most advanced countries. As indicated in section 4, during the 80s, specific policies aimed at the development of advanced materials were pursued. This period was marked by different attempts to alter the pattern of consumption and production of materials. The main objective was obviously to explore the possibility of establishing leadership in this strategic area.

In section 5, the analysis concentrates on the discussion of the main characteristics of Japan's long term policies for the development of advanced materials. The intense Japanese effort to build up a capability aimed at changing the materials base of future industrial development from metals to advanced ceramics is discussed.

In section 6, Impacts of the Introduction of AMs, the declining trend in "traditional" materials consumption and production is analysed. The consequences of such a movement are discussed. The central focus falls on the impact of such changes on those developing countries which are major producers of basic metals. Most of all, the fact that these recent changes lead to far more complex industrialization processes - where comparative advantages depend increasingly on innovation (both technical and organizational), rather than on purely physical factor endowment - is stressed.

2-Definition and Characteristics of Advanced Materials

Despite the growing importance attributed to the development, production and impact of advanced or new materials in the world economy, one could argue that the relatively few comprehensive studies yet undertaken probably fail to give an exact definition of these terms. Moreover, it can be pointed out that at least two aspects contribute to making the definition of advanced materials a difficult task.

Firstly, it can be considered that the terms employed to define these materials display rather static features compared with the dynamism of the area. This is not an exclusive characteristic of this specific area. The adoption of some adjectives (such as for instance: new, advanced, high technology, fine, etc) to qualify the development of new economic activities could be most criticized for lacking rigour.

However, most of those who try to define new or advanced materials do not usually go further than the definition *ipsis literis* that those adjectives permit. This kind of "keeping to the strict sense of the adjective" comprehension produces many sorts of difficulty. The first is the apparent paradox that relates to the fact that the "age" of each specific material (i. e., when it was discovered or formulated) does not really matter. Some of the so-called AMs consist of recently developed substances, as is mainly the case with the new ceramic superconductors. Some were developed two or even more decades ago (as with the cases of silicon, optical fibres and composites) and still others are established materials submitted to new technological improvements (as some advanced metals and alloys).

The second aspect to be considered is that if one pays attention to how many and what materials are being considered by the related literature as advanced, it will be conclude that they do not form what is traditionally called a homogeneous category, and also that there is no cabalistic quantity used to identify the so-called new or advanced materials.

The understanding one has about advanced materials will vary in accordance with many factors. As a result, the materials considered as advanced sometimes differ greatly from country to country or from institution to institution within the same country.

It would not be unfair to say that those who write about such a subject usually avoid confronting these problems. One could also argue that the greater part of the bibliography on advanced materials is much influenced by S & T evolution. This is quite understandable given the novelty of the subject and also its strong S & T basis.

As the majority of the authors who write about the issue have a strong technical background, it can be said that most of the attempts to define these materials tend to result in descriptions of: their impressive physical or chemical characteristics, properties and functions; their potential fields of application; the sophisticated processes used for their production; the purity required of their inputs, etc. Despite the high quality and importance of these studies, there is also the necessity to respond to, at the least, questions such as the following:

-What makes these advanced materials so important for the recent development of the world economy? What makes them so special?

-When were they developed and why are they being introduced into the market at this particular moment?

-Is it really necessary to establish a different category to distinguish these materials from others?

-What can actually be considered as advanced materials? In other words, where ought the boundary between advanced and traditional materials to be drawn?

In trying to answer such questions some authors define advanced materials as those developed to satisfy sophisticated and specific needs in response to the new requirements of market evolution or else as the result of scientific and technological advances.[1]

Regarding such definitions, the most important argument (which will be developed later on) refers to the fact that the recent changes cannot be considered simply as another incremental innovation in terms of materials evolution. And, most of all, what should be stressed here is that this is a movement guided by the perspectives of gains in competitiveness rather than considered as any natural or neutral kind of evolution.

Indeed, such a movement seems to be the very result of a vigorous effort towards the goal of opening up new areas of economic growth and gaining competitive advantages in national and international markets. With the development and diffusion of AMs, those countries and institutions (who have the necessary potential to understand and take advantage of the recent changes) are paving their way to increasing their competitiveness in both scenarios.

Advanced materials have been developed and (most importantly) are being introduced into the market in accordance with the main objectives emphasized by the new mode of world production introduced in the late 70s that is of saving raw-materials, energy and labour inputs and also of adding flexibility to the production processes.

In this sense, I would argue that the genesis, implications and impact of AMs are directly related to the long term changes in the techno-economic paradigm, as defined by Freeman, Perez, Soete, Dosi and others.[2] And in this precise context, I would suggest, advanced materials should be understood. The recent advances and changes in terms of materials evolution cannot be considered any more as the result of mere incremental innovations. Some of them consist in fact of radical innovations, which combined with incremental innovations, result in far reaching changes (either technical and organizational) needed to support the current techno-economic restructuring.

As the literature concerning long waves indicates, each period has been associated with the development of some industrial sectors and also

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[1] Among many others, Ray(1986), for instance, points out that: '**Many of the "new" materials were discovered or developed as the outcome of a specific need under wartime or market pressure. Others were the result of spontaneous and random scientific/ technological advance**' (p. 58). Flemings (1988 a) stresses that: '**The combination of "market pull" and "technology push" is driving structural materials forward at a faster rate than ever before in history**' (p. 31). Forney (1988) also agrees that: '**Two routes of research lead to innovative advanced materials: discovery-driven or market driven**' (p. 178).

[2] For instance in one of their work, Freeman and Soete (1987) found that in all sectors (despite the great variety of specific incremental and radical innovations in almost every industry) there was evidence of a change of 'paradigm' from the capital-intensive, energy-intensive inflexible, mass-and flow-production technology of the 1950s and 1960s to an information-intensive flexible, computerized technology in the 1970s and 1980s.

some groups of materials. The age of steam power was associated with the development of the coal and iron industries. The spread of the railways' systems was closely linked to the steel industry. Throughout the 20th. century the period of prosperity connected to the upsurge and consolidation of the car and electricity industries was strongly linked to the birth and development of the oil, chemical and metal industries.

In the same way, the development of advanced materials has been associated with the world's new production cycle led by information technology and, together with biotechnology, is seen as one of the three major areas that are now affecting and reorganizing the whole industrial basis as well as opening up new perspectives on development.[3]

Advanced materials can therefore be understood as those technology-intensive materials developed to fulfil increasingly sophisticated product specifications in order to satisfy the necessary conditions required for the establishment of this new economic cycle. In this sense, they reproduce, (and largely because of their pervasive role in the economy) consolidate and expand the main characteristics of the dynamics which are shaping the new pattern of international development, in other words, the new techno-economic paradigm.

Thus, the improvement of advanced materials is seen nowadays as one of the keys to the expansion and consolidation of new areas (such as information technology) as well as to the maintenance and restructuring of those sectors which are willing to strengthen their competitive power (as is mainly the case in the automobile industry). In this sense, the development of these so-called advanced materials (AMs) is seen as a vehicle for the transmission and diffusion of new styles of production. In these terms their evolution can be considered strategic.

The concept of advanced materials includes new metallic materials, advanced ceramics, new polymers and advanced composites.

Figure 1 shows different types of materials, within these four groups. It also shows the different functions that such materials can assume and gives examples of their main applications.

Among other features, should be pointed out the great diversity of functions (mechanical, thermal, electrical, magnetic, optical, chemical, biological and other special functions) displayed by the different types of materials.

As one result of the recent advances, nowadays, new polymers and composites with sophisticated mechanical functions are competing more and more with metals in structural applications. Advanced ceramics and new polymers can also compete with metals in terms of different applications which require thermal, magnetic, electrical and electronic functions.

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[3] Lastres et al (1988 a).

Figure 1.1: Functions and Applications of Fine Ceramics

Functions	Examples of Materials	Examples of Applications
<u>Mechanical Functions</u>		
High temp. strength	Silicon nitride, silicon carbide	Gas turbine, diesel engine,
Cuttability	Titanium carbide, tit. nitride, tungsten carbide, boron carbide	Cutting tools
Lubricity	Boron nitride, molybd. disulfide	Solid lubricant
Wearproof property	Alumina, boron carbide	Bearing, mechanical seal boring drill
<u>Thermal Functions</u>		
Heat resistance	Alumina, silicon nitride, silicon carbide, magnesium oxide	Electrode for MND generator heat resistant bearing
Thermal insulation	Potassium oxide-titanium oxide, aluminium nitride, zirconia	Heat insulators for high temp furnace, nuclear reactor
Heat transfer chars.	Boron oxide, silicon nitride, aluminium nitride, alumina	Electrical and electronics parts, radiator
<u>Optical Functions</u>		
Light transmitting	Alumina, yttrium oxide, barium oxide	Sodium vapour lamp, high temperature optical lens
Light inducing	Silicon oxide	Optical communication fibre, gastro-camera, photo sensor
Light deflecting	(Zirconium, titanium) acid (lead, lanthanum)	Photo-memory device (reversible)
Fluorescence	GaAs-rare earth ceramics, neodymium-yttrium series glass	Semiconductor laser, light emitting diode
Photo sensitivity	Silver halide containing glass	Sunglasses, image memory materials, window glass
<u>Electrical Functions</u>		
Superconductivity	Yttrium-barium-copper oxide, bismuth- strontium-calcium-copper oxide	Power generator, magnet, supercomputer, maglev train, linear motor car
Semiconductivity	Zinc oxide, barium titanate	Varistor, heater, solar cell, gas sensor
Piezoelectricity	Quartz crystal, lead zirconate titanate, lithium niobate	Ignition device, piezoelectric oscillator
Insulation chars.	Alumina, silicon carbide, beryllium oxide	Multilayer wiring board, IC package, IC printed board
Inducivity	Barium titanate, strontium titanate	IC microcondenser, high voltage service condenser
Ion/ionic conductivity	Zirconia, ß alumina	Enzyme sensor, solid electrolyte
Electron radiation	Lanthanum bromate	Cathode material for electron gun
<u>Magnetic Function</u>		
Magnetism	Iron oxide-manganese, iron oxide-barium oxide	Ferrite magnet, magnetic tape, memory device
<u>Biological Function</u>		
Histocompability	Alumina, apatite	Artificial teeth, artificial bone
<u>Chemical Function</u>		
Absorbing property	Porous silica, alumina, porous glass	Absorbent, catalyst carrier, bioreactor
Catalysing property	Zeolite	Catalyst for environment protection
Corrosion resistance	Zirconia, silicon oxide, alumina	Electrode for MHD generator high temp. reactor materials

Figure 1.2: Functions and Applications of New Polymers

Functions	Examples of Materials	Examples of Applications
Mechanical Functions		
High strength and durability	Polyester, polyamide	Various structural materials
Elasticity	Synthetic rubber, foamed plastics	Various structural materials
Shock and sound absorbing	Foamed plastics	Various structural materials
Surface protection	Coating films, electron beam hardened plastics	Coating materials, various paints
Adhesiveness	Polychloroprene	Various adhesives
Thermal Functions		
Heat resistance	Polyimide, silicone resin	Heat resistant structural mats
Low temperature resistance	Silicone rubber, fluororubber	Low temp. resistant rubber
Thermal insulation	Foamed plastics	Heat insulation materials
Electrical Functions		
Electric conductivity	Polyacetylene	Battery, electric wire
Insulation characteristics	Polyimide, polyethylene, terephthalate	Printed circuit board, condenser conductor
Energy convertibility	Polyvinylidene fluoride, doped polyacetylene	Sensor, eletroacoustic transducer device
Optical Functions		
Light transmitting	Polymethyl methacrylate acid polycarbonate	Optical fibre, plastic lens
Photo-active property	Photo-setting plastics	Copying materials, photo mask
Double refraction property	Liquid crystal	Display device
Biological Function		
Compatibility to blood	Polyethylene terephthalate	Artificial blood vessel, artificial heart
Histocompability	Silicone polymer	Artificial organ, artificial bone
Separating Function		
Ion exchangeability	Styrene group, acryl group	Ion exchange resins
Separation of mixtures	Cellulose acetate group, aromatics, polyamide group	Reverse osmosis membranes, air/gas separation and biological separation membranes
Chemical Function		
Corrosion resistance	Polybutane-1, polyamide, neoprene	Roofing materials, offshore Structural materials
Chemical resistance	Polychloroprene, butadien acrylonitrile	Flexible structure storage tank, fertilizer tank

Figure 1.3: Functions and Applications of New Metal Materials

Functions	Examples of Materials	Examples of Applications
Mechanical Functions		
High strength	Fine crystal alloy, single crystal alloy	Aircraft and space equipment
Superplasticity	Superplastic aluminium alloy	Aircraft
Vibration absorption	Magnesium series, manganese-copper series	Equipment members (vibration proof materials)
Thermal Functions		
Thermal resistance	Nickel base alloy, cobalt base alloy	Gas turbine, heat pipe
Electrical Functions		
Superconductivity	Niobium-titanium, niobium-3 tin, vanadium-3 gallium	Nuclear fusion reactor linear motor car
Semiconductivity	Amorphous silicon	Solar cell, sensor
Magnetic functions		
High magnetism	Samarium, cobalt	Magnetic recording, motor
High mag. permeability	Amorphous alloys	Transformer core, magnetic head
Others		
Hydrogen absorbing	Fe-titanium series, magnesium-nickel series	Transfer of hydrogen, hydrogen car, heat media
Super-high-speed electron mobility	Gallium arsenide	Super-high -speed IC (Josephson devices)
Shape-memory	Nickel-titanium series, copper-zinc series	Pipe joint, artificial joint artificial muscle

Figure 1.4: Functions and Applications of New Composites

Functions	Examples of Materials	Examples of Applications
Mechanical Functions		
High strength + light weight	Polymer based composite (Matrices: epoxy resins, fluorocarbon, engineering and superengineering plastics. Reinforcements: carbon fibre, boron fibre, aramid fibre, ceramic fibre)	Aircraft and space equipment automobile and railway cars, ships, leisure and sports goods
Thermal Functions		
Heat resistance + high strength	Metal based composite (Matrices: aluminium, copper, magnesium, titanium, nickel. Reinforcements: ceramic fibre, boron fibre, metal fibre)	Nuclear power equipment, gas turbine, aircraft and space equipment, heat exchanger
	Ceramic based composite (Matrices: alumina, silicon nitride, silicon carbide. Reinforcements: ceramic fibre, metal fibre)	Nuclear power equipment, gas turbine, aircraft and space equipment, rockets

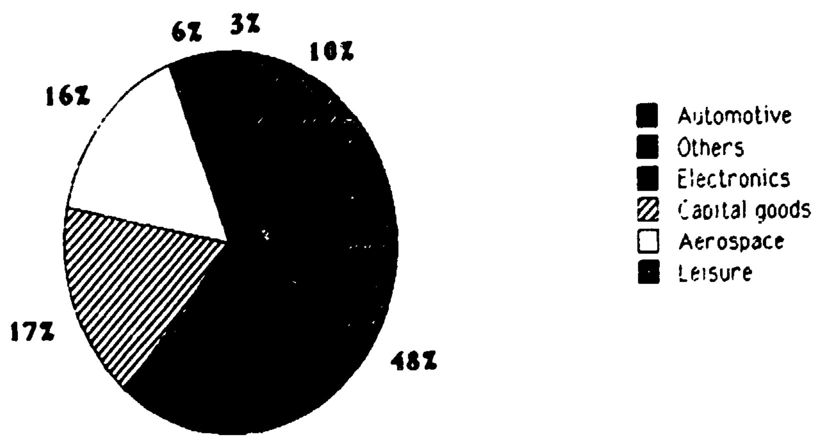
Source: JETRO (1986), Lastres (1988 a)

Regarding their different sectors of application, it should be pointed out, in Figure 1, those which are currently the most consumed AMs:

- electronics and information technology - silicon, compound semiconductors (such as gallium arsenide and indium phosphide), advanced ceramic substrates, photoresists, amorphous alloys and optical fibres;
- space and transport in general - superalloys, special light alloys, new polymers and composites for aircraft, space equipment, rockets, ships, automobile and railway cars;
- capital goods - advanced ceramics and special alloys (for drills, cutting tools, seals and sensors);
- leisure - composites (for fishing rods, tennis rackets and golf clubs);
- defence - composites and special alloys;
- biomedical - advanced ceramics, new metals and composites (for artificial teeth and bones) and new polymers (for artificial organs, blood vessels and skin).

Figure 2 shows the world consumption structure for advanced materials in 1986. From it, we can see that more than 80% of the total sales of AMs in that year (US$ 8.4 billion) refer to three sectors: electronics, capital goods and aerospace, the first being responsible for almost half of the consumption of advanced materials.

Figure 2: World Market for Advanced Materials by Industry
1986 Total Sales = US$ 8.4 billion



Source: Farth et al. (1988)

3 - Discontinuity in Materials Evolution

The development and introduction of advanced materials and the gradual substitution of them for so-called traditional materials consist in a process the consequences of which are being considered by many authors as a real "materials revolution". In this section, will be discussed the idea that a major discontinuity in materials evolution is taking place.

The main hypothesis behind this idea is that the advent of AMs constitutes a major discontinuity and that the establishment of a new pattern of production and consumption of materials is playing an important role in the process of industrial restructuring (affecting patterns of investment, organization, employment and trade) and is expected to lead to a major change in terms of the patterns of economic and technological leadership.

The four main arguments for such a hypothesis are discussed below.

3.1 - The recent changes are not incremental and originate from strategies adopted outside the traditional materials sector.

The analysis of AMs shows that the development and introduction of these materials have nothing to do with any strategy defined by the so-called traditional materials sector. On the contrary, the very development of the most important AMs seems to be a result of the attempts made to avoid the main constraints produced in and by the "traditional materials" sector mainly in the 70s and 80s.

The rapid increase in the price of raw materials, after the so-called oil crisis, the deregulated increase of production (with the strong entrance of very competitive developing country producers), the oversupplied markets and consequent losses experienced by this sector are the most discussed components of such a constraint.[4] Such a difficult situation contributed to an increase in the rigidity of the industries in this "mature" sector. The lack of new investment and the very low rate of R & D expenditure could probably be considered to be crucially important in terms of the low modernization that this sector experienced during this period. The exceptions were few.

The main innovations in AMs were, then, produced outside the traditional materials sector. In the same way, the appropriation of such development was mainly pursued by consumers of those materials, rather than by producers of traditional materials.

As shown in Table 1, there is indeed a large number of advanced materials consumers attempting a diversification into AMs. Such big Japanese, North-American and European firms belong to sectors such as:

- information technology and electric-electronics (AT&T, IBM, ITT, Texas Instruments, GE, Westinghouse, NTT, Toshiba, NEC, Matsushita, Mitsubishi, TDK, Sanyo, Sony, Sumitomo, British Telecom, Thompson, Philips, Ericson, ASEA- Brown Boveri and Siemens, among others);

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[4] See for instance: Souza (1988), US Bureau of Mines (1985), Gonzalez-Vigil (1985)

- aerospace and aeronautics (Boeing, Mac Donnel Aircraft, Aérospatiale); automobile (Isuzu, Honda, Nissan, Toyota, Ford, GM, Renault, Scania, Volvo and Fiat); and

- capital goods (Hertel, Krupps-Widia).

They are interested in all kinds of AMs and particularly, as indicated by Table 1, in the development of advanced ceramics.

Table1: Consumers of Advanced Materials - Diversification into Production

Firms	Advanced Materials
Fuji (JP)	adv. ceramics
Fujitsu (JP)	superconductors and adv. ceramics
Furukawa (JP)	optical fibres, new metals, superconductors and adv. ceramics
Hiteshi (JP)	opt. fibres, semiconds., superconds., adv. ceramics and new metals
Honda (JP)	adv. ceramics
Ishikowajima (JP)	adv. ceramics and new metals
Isuzu (JP)	adv. ceramics
Nissan (JP)	adv. ceramics and composites
NEC (JP)	semiconductors, superconductors, adv. ceramics and new metals
NTT (JP)	semiconductors, superconductors and adv. ceramics
Matsushita (JP)	new polymers, new metals, adv. ceramics and superconductors
Mitsubishi (JP)	opt. fibres, semiconds., superconds., adv. ceramics and new metals
Sanyo (JP)	adv. ceramics and amorphous silicon
Sony (JP)	adv. ceramics
Sumitomo (JP)	semiconds., superconds., adv. ceramics, opt. fibres and n. polymers
TDK (JP)	adv. ceramics
Toshiba (JP)	semiconductors, superconductors, adv. ceramics and new metals
Toyota (JP)	adv. ceramics and composites
AT & T (US)	adv. ceramics, new metals, semiconductors and superconductors
Bechtel (US)	composites and superconductors
Boeing (US)	composites
Energy C. D. (US)	superconductors
Ford (US)	adv. ceramics, composites and superconductors
Gen. Dynamics (US)	composites and superconductors
GE (US)	optical fibres, semiconductors, superconductors and adv. ceramics
GM (US)	composites, adv. ceramics and superconductors
Goodyear (US)	composites and adv. ceramics
J & J (US)	adv. ceramics
IBM (US)	adv. ceramics, new metals, semiconductors and superconductors
ITT (US)	adv. ceramics
Kaiser Aerosp.(US)	adv. ceramics, new polymers and superconductors
Mac Donnel Air.(US)	composites
Motorola (US)	adv. ceramics
Texas Ins. (US)	adv. ceramics and semiconductors
Westinghouse (US)	superconductors and adv. ceramics

Table1: Consumers of Advanced Materials - Diversification into Production (cont.)

Firms	Advanced Materials
CGE (FR)	adv. ceramics
Renault (FR)	composites
Aérospatiale (FR)	composites
Stettner (FR)	adv. ceramics
Thomson (FR)	adv. ceramics and optical fibres
British Telecom (UK)	adv. ceramics, superconductors and optical fibres
Oxford Instruments (UK)	semiconductors and superconductors
Plessey (UK)	semiconductors adv. ceramics and superconductors
Hertel (FRG)	adv. ceramics
Krupps-Vidia (FRG)	adv. ceramics
Siemens (FRG)	optical fibres, adv. ceramics and superconductors
Philips (NL)	optical fibres, adv. ceramics
ASEA-Brown Boveri (CH)	semiconductors and superconductors
Ericson (SW)	adv. ceramics
SAAB-Scania (SW)	adv. ceramics
Volvo (SW)	adv. ceramics
Fiat (IT)	adv. ceramics

Source: Yano Research Institute (1984), Long Term Credit Bank of Japan (1984), Cohendet et al. (1988), High Technology Business (1980), Sá (1989) and Lastres et al. (1988).

In fact, we have to consider that there are also some traditional metal producers who have entered the AMs sector. Table 2 shows some examples. Nevertheless, very few metal producers in the US and Europe have shown the interest or capability of entering such a new and high-tech sector.[5]

Only in Japan (where the development of AMs has been one of the main national priorities and where a government policy of restructuring took place) did metal producers display a marked diversification into AMs, as can be seen from Table 2.

[5] Cohendet et al. (1988), for instance, regarding the mas producers, argue that the 'European situation is marked by a relatively poor mobility of industrial structures, and the failure to switch to functional materials which in overall terms, after a period of adaptation, have taken over ... (There is a) manifest strategic sluggishness on the part of a considerable proportion of European companies when it comes to identifying future opportunities and to diversifying, the archetypal example being the steel industry.' (p. 346)

Table 2: Metal Industries Diversification into Advanced Materials

Metal Industries	Advanced Materials
Daido Steel (JP)	new metals
Hitashi Metals (JP)	adv. ceramics, semiconductors and new metals
Kawasaki Steel (JP)	silicon wafers, adv. ceramics, carbon fibre, supercs., n. metals
Kobe Steel (JP)	adv. ceramics, superconductors, composites and new metals
Mitsubishi Metals (JP)	semiconductors, adv. ceramics and new metals
Nippon Koken (JP)	silicon, n. metals, n. polymers, carbon fibre and adv. ceramics
Nippon Steel (JP)	new metals and adv. ceramics
Nippon Tungsten (JP)	silicon wafer, carbon fibre, n. metals, supercs., adv. ceramics
Sumitomo Metals (JP)	carbon fibre, semiconductors, new metals and adv. ceramics
Korean Steel (KO)	carbon fibre
Alcoa (US)	n. polymers, adv. ceramics, opt. fibres, composites and n. metals
Teledyne (US)	new metals and superconductors
Pechiney (FR)	ceramics, carbon fibre and new metals

Source: Yano Research Institute (1984), Long Term Credit Bank of Japan (1984), Cohendet et al. (1988), High Technology Business (1988), JETRO (1986), Sá (1989) and Lastres et al. (1988)

One important feature that should be stressed here is the fact that the diversification pursued by metal firms concerns also the production of substitutes for metals. These firms are pursuing the production of materials which are very different from their traditional productive and technological basis. The target seems to be the maintenance of their market share, threatened by the development of such advanced substitutes. As shown in Table 2, the Japanese steel companies are entering not only the field of production of new metals, but also [illegible] of advanced ceramics, new polymers and composites. The same is happening in the case of the French (Pechiney) and the North-American (Alcoa) aluminium companies and in the case of the Canadian (Noranda) copper company.

The metal industry's attempt to diversify into AMs faces strong competition from other traditional sectors which are also trying to restructure and diversify their activities. Among them the most important sectors are: cement, textiles, traditional ceramics, chemicals and petrochemicals. The petrochemical and chemical sector is, without doubt, the one which is most heavily investing in AMs and which has the best financial and technical conditions for doing so.[6]

In fact, the biggest petrochemical and chemical firms in the world (such as Du Pont, Dow Chemical, Exxon, Monsanto, Union Carbide, 3M, Basf, Bayer, Hoechst, Elf, Rhône-Poulenc, British Petroleum, ICI, Shell and Ciba Geigy) now include AMs in their strategy of diversification.

6 Ibid

Table 3: Petrochemical and Chemical Industries Diversification into Advanced Materials

Industries	Advanced Materials
Asahi Chemical (JP)	optical fibres, adv. ceramics, composites and new polymers
Idemitsu (JP)	new polymers and carbon fibre
Kureha Chemical (JP)	new polymers and carbon fibre
Mitsubishi Chemicals (JP)	adv. ceramics, semiconductors and new polymers
Mitsui Toatsu Chemicals (JP)	new metals and new polymers
Showa Denko (JP)	adv. ceramics, n. metals, carbon fibre, semics., n.polymers
Sumitomo Chemical (JP)	adv. ceramics, carbon fibre and new polymers
Toho - Rayon (JP)	composites and new polymers
UBE Chemical (JP)	adv. ceramics and new polymers
Allied Chemicals (US)	new polymers, composites, semiconductors and new metals
Dow Chemical (US)	adv. ceramics and new polymers
Du Pont (US)	new polymers, composites, adv. ceramics and supercs.
Eastman Kodak (US)	new polymers and adv. ceramics
Exxon Chem. (US)	new polymers
Hercules (US)	new polymers and composites
Monsanto (US)	new polymers
Union Carbide (US)	silicon, composites, adv. ceramics and new polymers
3M (US)	adv. ceramics, composites, and new polymers
Basf (FRG)	carbon fibre, composites and new polymers
Bayer (FRG)	adv. ceramics and new polymers
Feldmüle (FRG)	adv. ceramics and new polymers
Hoechst (FRG)	adv. ceramics and new polymers
Elf (FR)	adv. ceramics and new polymers
Rhône-Poulenc (FR)	adv. ceramics and new polymers
BP (UK)	composites
ICI (UK)	composites, adv. ceramics, supercs. and new polymers
Shell (UK+NL)	carbon fibre and new polymers
AKZO (NL)	carbon fibre and new polymers
Ciba Geigy (CH)	composites and new polymers

Source: Yano Research Institute (1984), Long Term Credit Bank of Japan (1984), Cohendet et al. (1988), High Technology Business (1988), JETRO (1986), Sá (1989) and Lastres et al. (1988).

As Table 3 shows, these firms are mainly pursuing the production of new polymers, composites (and/or carbon fibre) and advanced ceramics. Elsewhere I emphasize that the Japanese efforts in this direction (even if recognized as relatively weak for the time being) cannot be ignored.[7]

[7] See for instance the recent attempts in Japan to strengthen this sector and to establish the concept of "New Chemistry" (linking the development of chemistry with, for instance, electronics). Lastres (1989 c)

3.2 - The development of AMs offers the possibility for an inversion in the logic of production.

This second argument refers to the fact that nowadays a major advance in the means of analysing and understanding the structure and properties of matter has been obtained. The cross-fertilized effects and fusion of materials science with other disciplines such as chemistry, metallurgy, physics, electronics, biology, computer science and engineering, etc have led to significant improvements and developments in materials analysis, design, processing and testing (such as powder technology, hot isostatic pressing, rapid solidification process, coating and surface modification, bonding techniques and non-destructive testing methods).

It is possible now to intervene at the molecular and atomic level of matter and rearrange the microstructure of materials in order to obtain the required properties and performance. This has been considered a crucial development that set the basis for the beginning of an inversion in the logic of production. The focus of the new production systems tends to concentrate more and more on specifications to be met and capabilities to be realized, instead of type of materials (or mineral input) to be used. In other words, a given product no longer relies on a given material or on a given input, instead, several materials compete to assume a given function (concept of "hyperchoix des matériaux").[8]

Another important aspect related to this second argument and which is characteristic of this new production system is that the linkages between research, design, production, marketing and consumption were strengthened in order to permit the development of "tailored" materials for specific applications and environments.

3.3 - The development, design and production of advanced materials rely on the use of information-intensive techniques and require new patterns of work organization and industrial organization.

It is important to stress, not only the recent changes in terms of the use of inputs, but also the agility and flexibility brought about by the use of information-intensive techniques in the new materials production systems. The use of computational methods in the research, development, design, production, testing and commercialization of AMs permits a systemic approach, speeding up and augmenting the efficiency of the whole process. A significant example here relates to the utilization of CAD/CAM in order to obtain a "first best" mix among various materials and calculate systemic relations between shape and structure.[9]

It also seems important to emphasize that the use of these information-intensive techniques has been accompanied by new patterns of work organizati and industrial organization. Inflexible mass production which characte..zes traditional materials production systems has become

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[8] Cohendet et al. (1988).

[9] See Lastres & Cassiolato (1989).

increasingly unsuitable in conditions of product differentiation, consumer sophistication and fast technological changes. The new plants designed to produce AMs are supposed to be flexible enough to allow the production of "tailor-made" and use-specific materials. Such plants are operated by "multiskilled" labour forces and are frequently designed to produce "multimaterials".

3.4 - This materials revolution is leading to a long term structural change that can be characterized, on the one hand, as a "transmaterialization" of production and, on the other hand, by a "dematerialization" of production.

The concept of transmaterialization of production refers to the recurring industrial transformation in the way that societies use materials, which is a regular and cyclical process. Dematerialization of production, in its turn, refers to a constant decline in the use of materials as a percentage of total production. This latter concept relates to three main aspects. Firstly, the bold degree of miniaturization achieved by industrial production is seen as an important factor in decreasing the requirements of materials needed by industrial processes. Secondly, the increasing use of information technology in the production of materials and products has also been responsible for a considerable saving of materials. Thirdly, there is the fact that the material itself is visibly tending to gain in complexity by "integrating" several functions.

Data showing the declining trend of the consumption and production of traditional materials has been produced in order to support the idea of transmaterialization and dematerialization of production. Such a trend is already clear especially in advanced countries' markets. Figure 3, for instance, shows the declining trend in intensity of basic metals consumption (Kg per unit of GNP) in Japan, which started 16 years ago, just after the oil crisis. Accordingly to this figure, such an inversion is most marked in the cases of steel, zinc and aluminium.[10]

Figure 4 shows the declining trend in the intensity of metal usage (metric tons per million US$ of GDP) in the US and in the world. The data, produced by the US Bureau of Mines, refer to the cases of steel, aluminium and copper. In the same way, the inversion of the consumption trend seems to be associated with the oil crisis.

Data relating to metals production in the US show that this declining trend in consumption reinforced the same trend in the production of the five major basic metals (Figure 5).

One strong argument produced by some analysts of such movements refers to the link of these trends to the generalized and temporary difficulties the US economy faced at the beginning of the 80s. However, as Figure 6

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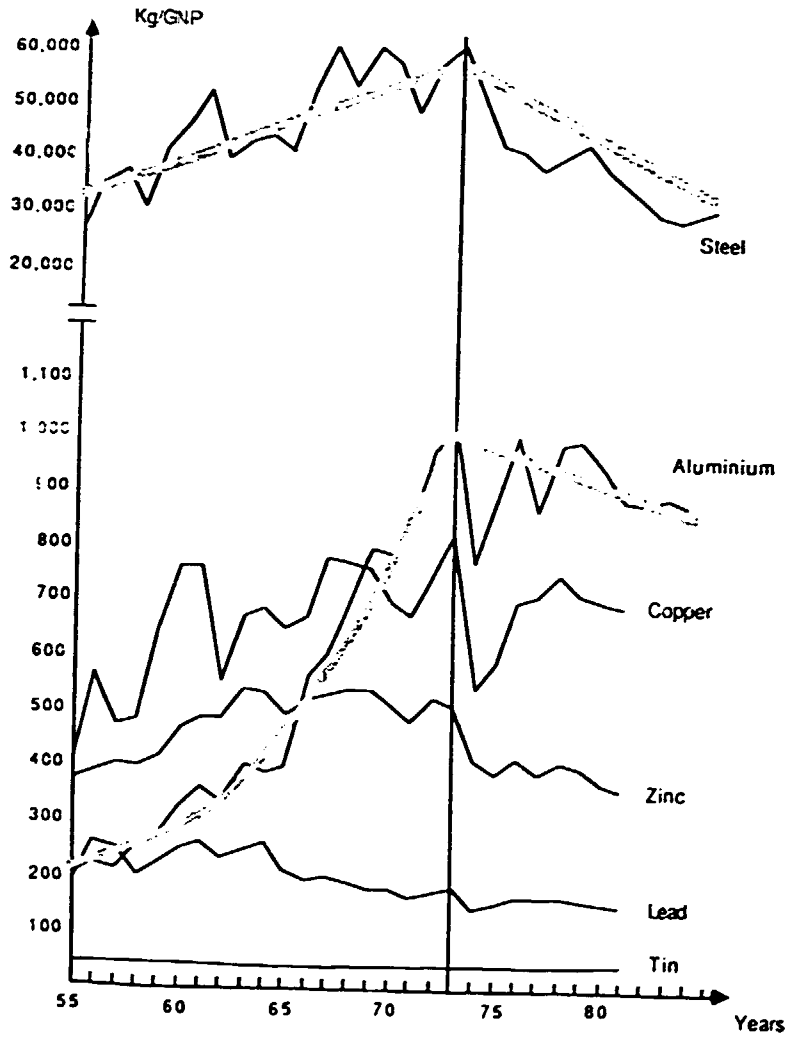
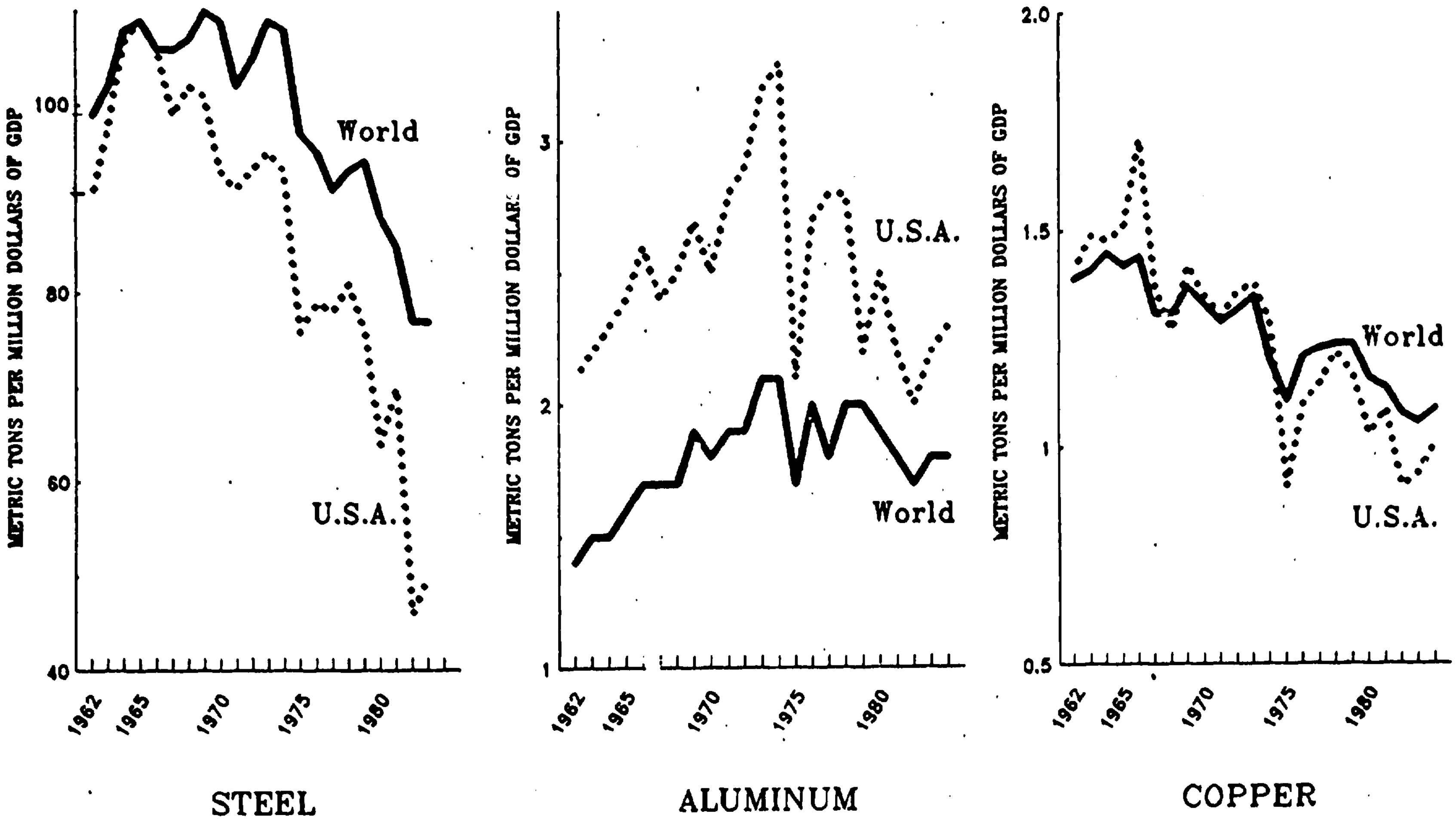
[10] Different sources show the same trend. The originality of those data used in Figure 3 refers to the fact that its primary source is the big French producer of aluminium, Pechiney.

FIGURE 3: Metals Consumption per unit of GNP in Japan (1955/84)



Source · Cohendet et al. (1988)

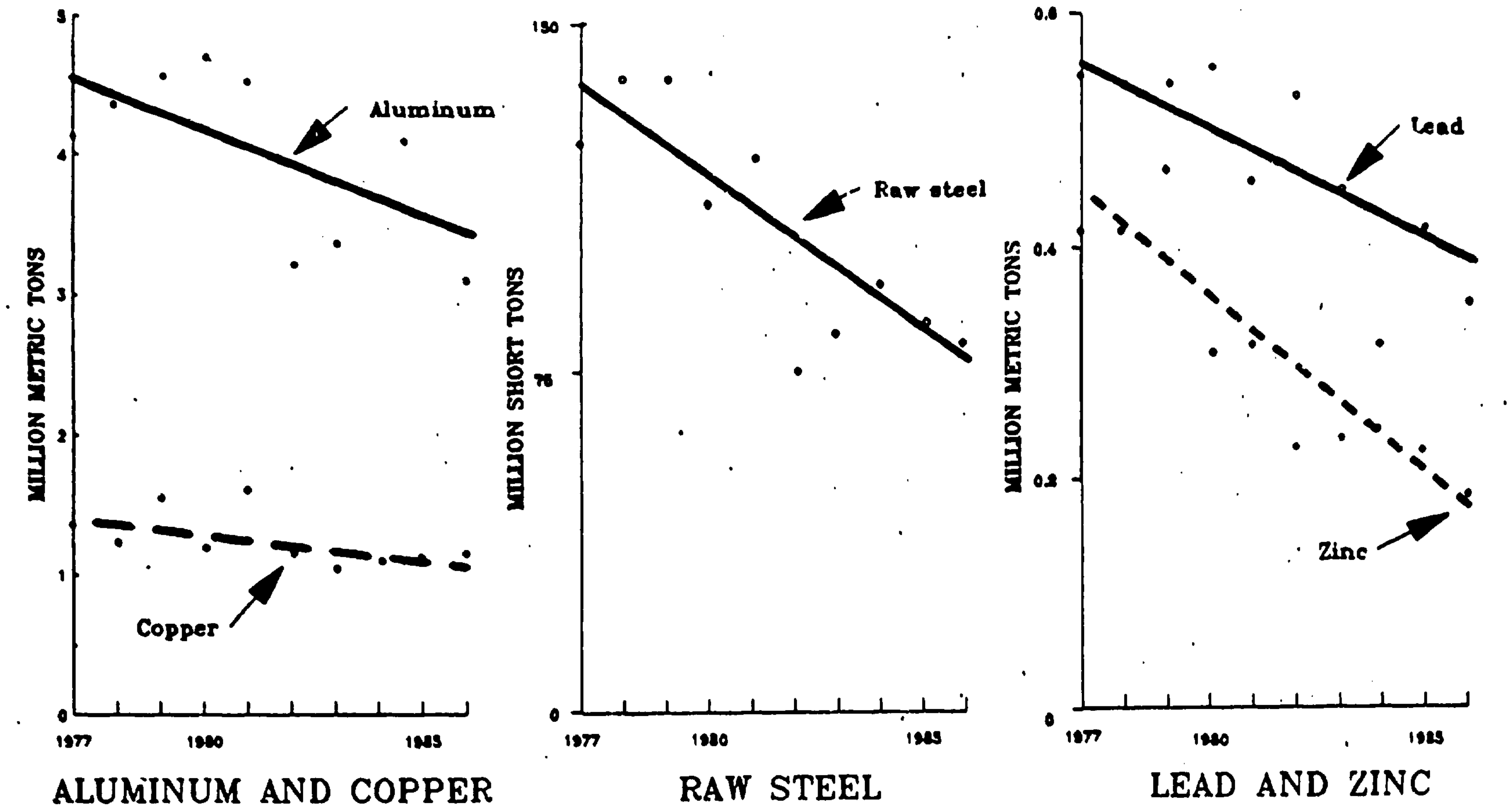
FIGURE 4: TRENDS IN THE INTENSITY OF METAL USAGE



Source: Souza (1988).

FIGURE: 5

THE DECLINING TRENDS IN COMMODITY METALS PRODUCTION IN THE UNITED STATES

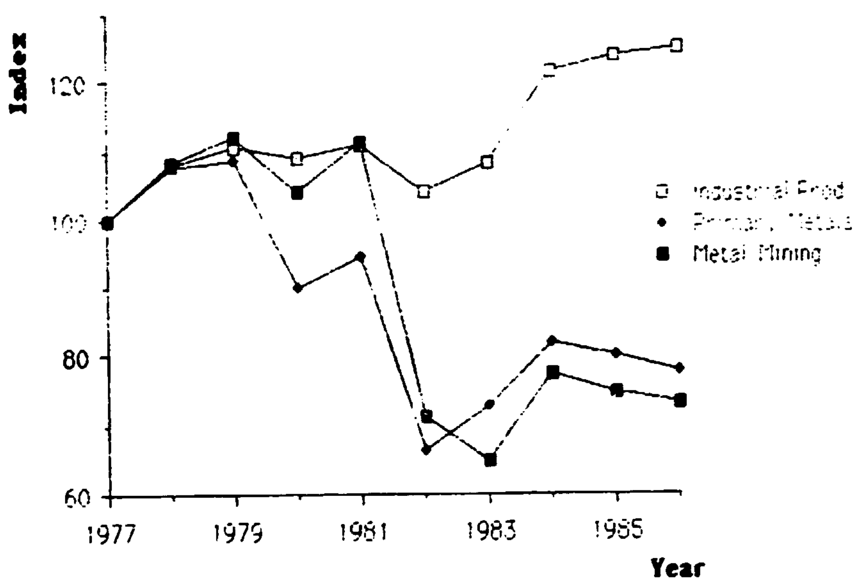


Source: Souza (1988).

One strong argument produced by some analysts of such movements refers to the link of these trends to the generalized and temporary difficulties the US economy faced at the beginning of the 80s. However, as Figure 6 indicates, such trends, at least in the case of the US, cannot any more be considered simply as a conjunctural shift.

As Figure 6 shows that the general recovery experienced by the US economy after 1982 was not followed in the primary metals sector and the metal mining sector, suggesting that the possibility of a structural change should be further investigated.

Figure 6: Industrial Versus Metal Production Index



Source: Souza (1988)

There is indeed a well defined tendency towards the process of AMs being substituted for basic metals, as is mainly the case with some polymers and composites displacing steel in the car industry or optical fibres displacing copper wires in telecommunications. Another aspect that relates to the fourth argument is that the advent of AMs goes beyond the process of materials competition and substitution. Opportunities are open for the development of entirely new materials displaying new properties.

As I have already mentioned, most of these AMs have been developed to fulfil completely new and sophisticated functions and applications, especially those associated with the advance in the high-tech areas. In this sense, they do not have to compete with existing materials in order to get into the market. Examples in this case include the development of semiconductor materials, photoresists and memory shape alloys, among others. The decrease in cost and price of such new materials will then be crucial in terms of permitting and accelerating their rate of diffusion throughout the economy as well as making possible the consolidation of these high-tech areas.

Therefore, perhaps the most important aspect relating to the development of these AMs is the fact that they have been seen as a necessary and strategic issue in terms of opening new paths of growth and strengthening future industrial competitiveness. Probably the best example of such a situation is the intense Japanese effort in respect of advanced ceramics. The long term policies adopted in that country towards the development of these materials seem to reflect the aim of building up capabilities aiming at establishing of a new pattern of production and consumption of materials.

So the development and introduction of AMs indeed seems to constitute a discontinuity in terms of materials evolution. Not only are the producers of traditional and advanced materials completely different, but also their inputs, technological processes, industrial structures, work organization, product characteristics (and frequently even their markets) are entirely distinct. The very group of materials which will form the basis for future industrial development is now being defined. A new sector is taking shape. In this sense, the current time presents an opportunity to establish a new technological and economic leadership in such a pervasive area.

4- National and Regional Policies on Advanced Materials

The major advances in materials science until the mid-seventies were mostly as the result of a spin-off from the huge US programmes in the areas of defence, aerospace and energy technology.

The decade of the 80s is marked by the generalized increase in R & D expenditure and, particularly in the case of AMs, by the formulation of private and national R & D projects concentrating attention on specific improvement of those materials.

4.1 - Japan

In Japan, the long term R & D policies on advanced materials have been coordinated by MITI and STA. Having started almost 20 years ago, from a rather modest basis and within the programmes on the conservation and the development of new sources of energy, materials projects have had the support of several industries.

Much more than in other countries, in Japan the development of advanced materials seems to have been pursued within a national framework of objectives. Firstly (and just after the oil crisis), the central target was related to the possibility of attenuating the impact of the increase in the price of oil and other raw materials on the Japanese economy. Nowadays, the hope of taking advantage of a promising structural change seems to be getting stronger in that country. The general idea is to establish a new pattern of materials production and consumption more adequate to the Japanese perspectives of growth. One attempt in this direction is the intention of changing the basis of future industrial development from metals to advanced ceramics. Such a possibility has been pursued by exploring the advantages created by the sound Japanese microelectronics sector, linking the development of AMs with the requirements of this sector.

Table 4 shows the Japanese R & D programmes on AMs in 1988 and 1989. In 1988, ¥ 16,070 million were deployed in this area, within the three main important governmental programmes in terms of materials (BFTI - Basic Technology for Future Industries, Large-Scale Project and Multi-Core Project[11]). From this total, 70% referred to R & D in superconductors.

In terms of the nature of AMs, the Japanese efforts in R & D concentrated on advanced ceramics. This family of materials in 1988 was responsible for almost 70% of that total, mostly because of the high priority given to R & D in high temperature ceramic superconductors (HTSCs).[12]

Table 4: R & D on Advanced Materials in Japan 1988/89 (million ¥)

Targets	Period (FY)	Budget (FY88)	Budget (FY89)
MITI (BTFI)			
Superconductors	1988/97	1061	1872
Advanced Ceramics	1981/92	1099	1149
New Polymers	1981/90	532	530
Synthetic Membranes	1981/90	357	358
New Metals	1981/88	380	-
Composites	1981/88	548	-
Photoactive Materials	1985/93	234	318
Large-Scale			
AMs Proc. Systems	1986/93	1679	2329
Fine Chemicals	1988/95	20	275
Subtotal		5960	
STA(Multi-Core)		11171	
(-BFTI)		(-1061)	
Total		16070	

Note: AMs are also developed within other MITI and STA projects, such as Human Frontier Program, Moonlight (Superconducting Generator), Sunshine, Large-Scale (High-Speed Computing System-GaAs), and also other ministries programmes Education, Post and Telec., Health etc).

Source: AIST/MITI (1988 and 1989) and STA (1988 a and 1988 b)

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[11] The latter includes R & D projects coordinated by STA, MITI, Min. of Education, Min. of Transport and Min. of Post and Telecommunications.

[12] Considering that only 8% of the superconductors programmes refer to metallic materials and also considering the efforts towards the development of structural ceramics (6%).

It is worthwhile mentioning that until 1987 (i.e. before the discovery of the HTSCs), the attention of the Japanese government was concentrated on the development of structural advanced ceramics. MITI, for instance, dedicated 20% of its BFTI total budget for 1987 (which in addition to AMs, included also electronics and biotechnology R & D) to these materials.[13] MITI budget regarding the research in structural ceramics (aiming at the development of gas turbine components) continues to increase year by year. From 1988 to 1989 it increased by 4.5%. Nevertheless, superconductors funding increased by 76% in the same period.

The most important result of these long term Japanese efforts is the leadership achieved by its industry in terms of the world hierarchy in the production of advanced ceramics (both electronic and structural), carbon fibre and semiconductors. In addition, Japanese capability in compound semiconductors (such as gallium arsenide), integrated optical materials, superconductors and biomaterials are being recognized as the most promising in the world.[14]

4.2 - United States of America

In the US, the emphasis on the development of AMs has concentrated on composites and new polymers (and, recently, also on superconductors). Currently, government sponsored R & D is diffused throughout the multitude of government programmes and there is no single agency having the sole mandate for materials R & D. This has been criticized by the US Congress and the scientific community, who attribute the recent Japanese leadership in strategic advanced materials to the US' lack of planning and coordination.

In fact, a recent survey on advanced materials produced under the auspices of the US National Research Council reinforces such conclusions.[15] The study comprises an analysis of advanced materials commitments in countries such as the US, UK, FRG, France, Spain, Canada, Japan and South Korea. The main conclusions are that:

- materials research and development seems to be less coordinated in the US than in other advanced countries. In the US no major agency is in charge of planning, setting priorities or evaluating materials (or industrial) policy and there is low cooperation (or no relationship at all) between various agencies and various sectors (especially between the generation of new knowledge and its utilization);

- most other nations support the development of materials science through carefully targeted government programmes;

- between 1976/87, the Federal government reduced materials funding by 11% and by 23% for nondefence spending;

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13 See Lastres (1989 b)

14 See Morse (1989).

15 Cohen (1989) and High-Tech Materials Alert (Dec. 1989).

- while the government gives defence and energy research that same type of national push, it leaves materials development for electronics, telecommunications, nonmilitary aerospace, and other fields in the hands of individual corporations.

- such a tendency has dangerous consequences for US competitiveness. The recent negative performance of 7 major industries, in terms of the balance of trade, has been attributed to the lack of sufficient progress in advanced materials.

The final recommendation of the report is that advanced materials offer a special opportunity to start urgent coordination in science and technology in general, which is lacking in the US nowadays. But, probably, the strongest argument used to attract better support for this area relates to the possible threat in terms of national security that the underdevelopment of these materials and their corresponding technologies could imply[16].

As one result of such pressures a recent change in the US is taking place. AMs are now seen as "an enabling technology inextricably linked to technological advancement and competitiveness as well as to national security".[17]

The North-American expenditure in AMs are estimated to be over tenfold the Japanese funding. The US has had the capacity to advance on a wide materials research front, which indeed requires a large budget. Then, and despite all criticism, the US still holds a comfortable international position in composites, new metals and new polymers and also in infrastructure and human resources capabilities in general.

Figure 7 shows that the Federal government spends US$ 1 billion every year in materials science and engineering in the US. This total includes AMs.[18]

As we have already seen, R & D responsibility in materials R & D programmes fall under the ambit of a number of agencies with specific mission targets. These include: Department of Energy, Department of Defence, National Aeronautics and Space Administration, Department of Commerce (National Bureau of Standards), Department of Interior (Bureau of Mines) and the National Science Foundation.

According to this Figure 7, DOE has been the most important promoter of materials R & D, responsible for almost 60% of the total expenditure in 1985.

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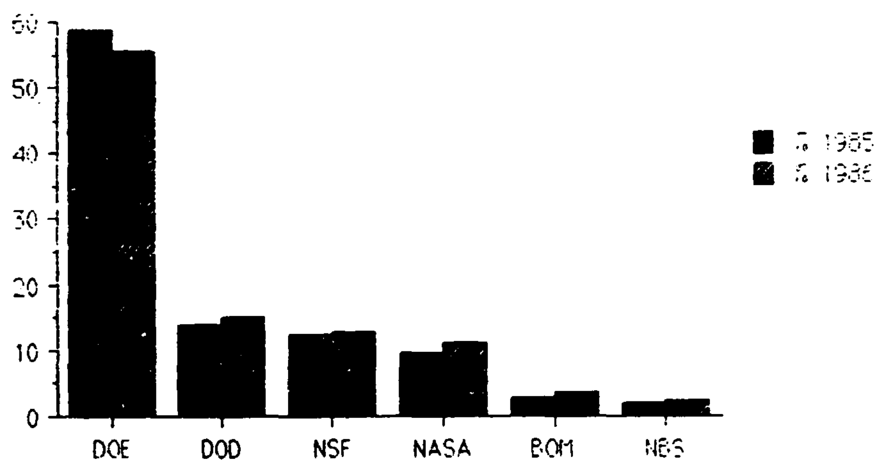
16 See, for instance, Morse (1989): **'When Japan was identified recently to be significantly ahead of the US in six of 22 critical technologies (microelectronics, compound semiconductors, machine intelligence, integrated optics, superconductivity and biotechnology materials) all critical to long term qualitative superiority in weapons systems, Americans saw this as a threat.'**

17 OECD (1988).

18 Reliable data for this area are not routinely available and, as OECD (1988) reports, probably are not separately tabulated. See note 8.

In 1986, DOE budget decreased from US$ 647 million to US$ 609 million. In the same year, all the other agencies increased their funding: DOD (from US$ 155 million to US$ 164 million), NSF (from US$ 135 million to US$ 137 million), NASA (from US$ 107 million to US$ 121 million), BOM (from US$ 33 million to US$ 41 million), NBS (from US$ 23 million to US$ 25 million).

Figure 7: R & D Materials Science and Engineering in the US by Agency
FY 85 = FY 86 = US$ 1.1B*



* It is estimated that private investment represents an equivalent amount.

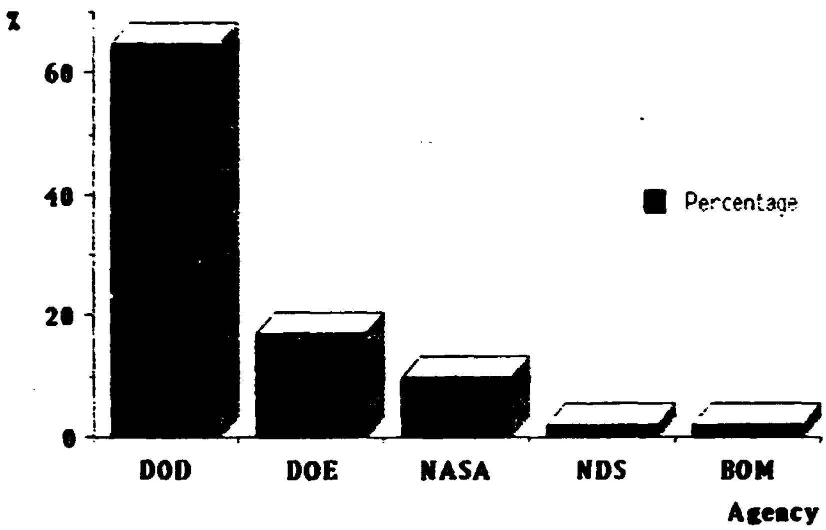
Source: OECD (1988)

It is estimated that, in the US, private investment represents an amount at least equivalent to the government investment. Among the main firms investing in AMs are: IBM, A T & T, Du Pont, Exxon, 3M, GE, Boeing and GM.

Specific data about R & D programmes on AMs in the US, shows a different picture. As Figure 8, indicates, in 1983, DOD was responsible for 65% of the total government funding. DOE for 17%, NASA for 10% , NSF for 4% and both NBS and BOM for 2%.[19]

[19] Data here refer to the survey the General Accounting Office made for FY 1983, based on data provided by the six main agencies in charge with AMs programmes, which totalled almost US$ 200 million. See OECD (1988 b)

Figure 8: R & D in Advanced Materials in the US by Agency (1983)



Source: OECD (1988)

Table 5 shows the R & D priorities in the US for materials in 1986. The most outstanding difference from other national policies relates to the emphasis on composites. Such an emphasis has been very strong there, where materials science has been much improved mainly because of the huge R & D programmes in defence technology.

Table 5: Government R & D Priorities in the US (1988)

Materials	Goals
Advanced Ceramics	
High-Perfomance Structural Ceramics	Dev. of mats. for heat components, turbine blades and heat shields for automotive and aircraft engines
Electronic and Superconducting Ceramics	Dev. of mats. for electronic and electrical components and for integrated optics for use in electrical transmission, transport and medical industries
Composites	
Fibre Reinforced Plastic Resin	Dev. of structural components for aerospace, automotive and ind. construction
Metal Matrix Composites	Dev. of mats. for structural and superconducting components
New Metals	
Amorphous Metals	Dev. of mats. for electromagnetic equipment

Source: OECD (1988 a and 1988 b)

As we can see from Table 6, in 1983, composites were responsible for more than half the government funding for AMs. Such a fact reflects the importance of DOD and NASA funding and their priorities for the development of such a family of materials.

Advanced. ceramics with 23% of the total funding in that year, was the first priority in DOE, BOM, NBS and NSF programmes.

New polymers, second priority for DOE, NSF and NBS, were considered at the time (as they are still considered nowadays) the most important area in terms of private capabilities. Governmental support in this area (expected to be supplementary to private investment) concentrated on new polymers with optical functions (mainly liquid crystal) and separation membranes.

Table 6: R & D on Advanced Materials in the US by Agencies (1983)

	DOD	DOE	NASA	NSF	NBS	BOM	TOTAL
composites	68%	7%	75%	1%	6%	-	53%
adv. ceramics	13%	6%	1%	34%	49%	53%	23%
amorphous alloys	15%	9%	13%	31%	21%	47%	15%
new polymers	4%	24%	2%	33%	24%	-	9%

Source: OECD (1988 a and 1988 b)

4.3 - Europe

Since the early 80s the EEC has included the development of AMs in strategic research programmes such as Sprit (VLSI integrated circuits), Race (optical fibres), Biotechnologie (biomaterials), Brite (separation membranes, new polymers, composites and amorphous alloys) and Eureka.

Eureka includes, among others (see Table 7) the project "Car Structure Using New Materials - CARMAT 2000). This project has a 5-year budget of 60 million ECUs and European firms such as Basf, Bayer, Elf, ICI, Pechiney, Peugeot and Saint Gobain participate in it.

Table 7: Materials in the Eureka Programme.

Nature of project	Projects approved end 1986 (Stockholm)	Cost (M ECU)	Duration (years)
	(nb D = Germany, CH = Switzerland, E = Spain, S = Sweden, F = France, N = Norway, Netherlands, A = Austria, I = Italy, GB = GB)		
EU 3 Amorphous silicon	Solens (F) - MBB (D)	53	5
EU 5 Filtration membranes	Lyonnaise des Eaux (F) Dégrémont (F) - De Danske Sakker Fabriken (DK)	56	6
EU 13 CARMAT 2000 Development of solid automobile structures, ultra-light fibres	Peugeot (F) - BASF (D) Battenfeld Extension Technic (D) - Bayer A.G. (D) - Cristaleria Esp.(E) Ecole des Mines (F) - Elf (F) - Pechiney Alu (F) - Saint-Gobain Vitrage (F) Usinor (F) - Vetrotex (F) DSM (NL) - ICI (GB)	60	5
EU 25 Aluminium in place of chromium in treatment of leather	(Spain) - (Germany) (GB)	25	3
EU 29 Development of new ceramics for car engines	Desmarquet (F) - Péchiney Alu (F) - Peugeot (F) - Fiat Holding (I)	15	5
EU 33 Ceramics in gas turbines	SEP (F) - Hispano Suiza (F) - Snecma (F) - Alfa Romeo (I) Volvo Slygmotor (S)	16	5
EU 40 Construction technologies (infrastructures and networks for major building developments)	Giblin (D) - SAE (F) - Società Costruzioni Generalisti (I) Bovis Construction LTD (GB) - Charcon Tunnel (GB)	9.2	5
EU 42 Light-weight materials for transport systems	VAW (D) - Institut fur Angewandte Stahlentechnik (D) KSR (D) - Péchiney Alu (F)	15	4
EU 47 Ceramics for diesel engines	Mann (D) - SEP (F)	14	5
EU 52 Disposable sensors for the medical field	(Netherlands) - (Switzerland) - (Belgium) (Germany)	4	5
EU 96 Super-conducting coils	Université de Genève (CH) Société Elin-Union (A) - Metall-Werke Plansee (A) - Technishe Universität Wien (A) Spectro A.G. (CH)	8	3
EU 102 EPROM (Integrated Circuit Non-Volatile Memory). Memories with a capacity of 16 M bits	(France) - (Italy)	400	5
EU 113 Development of lasers (solid state included)	(France) - (GB)	180	6
EU 117 Fibre-reinforced plastics, glass fibre, composites	(Finland) - (Belgium)	2 to 3	2
EU 127 JESSI (Joint European Sub-micron Silicon). Sub-micron technology	(Germany) - (GB) - (France) - (Netherlands) (Italy)	2.4 to 2.8	10
EU 132 Transmission by optical fibre systems	(GB) - (Sweden) - (Portugal)	8 to 16	2 to 2.5
EU 138 Coatings for advanced technologies	Coat A.B. (S) - Lebolt Heraeus (D) - Flort (S) - Volvo (S) - Imcol (GB) Pilkington (GB)	4.5	4
EU 139 Methods of forecasting properties of (injection moulded thermoplastic articles	Royal Technology Institute (N) - Centre for Industrial Research (S)	1.6	5
EU 155 International co-operative research for laser applications	(Germany) -	7.5	3
EU 159 EURODYN (Programme demonstrating technology of gas turbine engine)	(France) - (Netherlands)	33.8	4
EU 160 Development of mineral membranes and procedures for separating fermentation products (antibiotics)	(France) - (Italy)	14.7	4
EU 162 Electron beam treatment : applications in processing industry (micro-emulsions, polymer granules)	(Sweden) - (Finland)	3.3	3
EU 163 EUROVISI (display systems)	(Ireland) - (GB)	1.6	3.5
EU 164 Microencapsulation, development of new sensors, pharmaceutical industries	(Finland) - (GB)	0.5	-
Projects pending			
Thin films and deposit on materials (EU 66) (electronic, lubrification)	Lausanne Ecole Polytechnique and other Swiss bodies	1.1	2
New process for polymer production (EU 74) (fermentation, lactic acid)	Spanish companies	-	-
Production line for mass-market integrated sensors	Metravibe (F) - CSEM (CH)	-	-
Flexible automated microlithograph line, for integrated circuits	MATRA (F) - CNET (F) - Cambridge Instruments (GB) Frauenhofer Institut (D) SGS (I), etc...	-	-
Inspection and automatic testing of integrated circuits	Electronique Serge Dassault (F) - CSEM (CH) BATELLE (CH)	5	3
Advanced microprocessors, GaAs integrated circuits, microwave components, high-density memories, flat screens, sensors)	Thomson (F) - GEB (GB) - Philips (Netherlands) - Siemens (D)		-
Flexible automated factory for manufacture of electronic equipment	Eurosoft (F) - CSEA (I) - Inisel (E)	28.8	5
Non-invasive medical diagnosis equipment (biosensors and IA)	(France) - (DK) (Spain)	-	-
Custom-built integrated circuits (ES2)	(Luxembourg) - (Germany) - (GB) - (Belgium) - (Finland) (Sweden) - (Switzerland) (Austria)	105	3
Materials and new assembly technologies for transport	Péchiney (F) - VAW (D)	-	4
New materials for semi-trailers	Berlin (F) - Vetrotex (F) - Solvay (B) GKN (GB) - Fruehauf (D), etc...	-	-
Medium-power ceramized gas turbines	SEP (F) - Hispano Suiza (F) - Volvo (S) - Alfa Romeo (I)	16	5
Materials and computer-assisted design and manufacture	Aérospatiale (F) MBB (D)	-	-
Broad-band telecommunications	CIT-Alcatel (F) - Italtel (I) - Plessey (GB) etc...	-	-
Full automation of chip assembly	Matra (F) - SGS (I)	-	-
Computer-assisted design and manufacture of GaAs integrated circuits	Thomson (F) - GEC (GB)	58.5	[illegible]
Thyristors for high-power application in rail traction	Thomson (F) - GEC (GB)	18.5	[illegible]

Source: Cohendet et al (1988).

In 1986, a special programme on AMs was established - the European Research for Advanced Materials (EURAM). The basic document of this programme explicitly recognizes the significant results achieved by Japanese and North-American firms as an outcome of R & D expenditure in AMs and the consequent inferiority of European firms in facing such increasingly difficult competition.[20]

This is a four-year programme with a budget of 30 million ECUs. Its main target is the development of those AMs in which Europe is relatively less competitive: advanced ceramics, new metals and composites (see Table 8). It aims at the improvement of materials, linking basic research with engineering work and it is designed to create, develop and apply new materials and to secure the evolution of existing materials to a higher level of improvement and to be competitive in terms of costs.

Table 8: European Research for Advanced Materials - EURAM Programme

Priorities	Goals
Development of Metallic Materials:	aluminium alloys (especially for aerosp. and aut.)
	magnesium alloys
	titanium alloy
	electrical contact materials
	magnetic materials
	mats. for surface coating (dev. of new steel alloys)
	development of improved thin-walled casting
Development of Advanced Ceramics:	optimization of SiC, Sialon for use in engines
	mats for surface coating (substitutes for metals)
	basic study of the high-temperature behaviour
	study of ceramic composites
Development of Composites:	organic-matrix composites (for aerosp. and [illegible])
	metallic-matrix composites (using aluminium and magnesium matrices)
Other AMs for Specific Applications:	memory shape alloy, alloys with high energy absorption, highly corrosion resistant marine materials, composites with amorphous matrices, composites with vitreous matrices and composites with elastic matrices for energy-shock-noise absorption

Source: EURAM (1986)

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20 **Pour sortir de ce cercle vicieux de vulnérabilité et de dependance, et aussi pour regagner sa compétitivité sur le plan mondial, l'industrie européenne doit investir massivement dans l'innovation technologique des matériaux. Le project EURAM, en regroupant les entreprises matériaux de la CEE en un ensemble cohérent, peut jouer le rôle de catalyseur pour promouvoir une véritable science et un génie des matériaux européens.'** CEE, Programme d'Action de Recherche - Materiaux 1986/89 (Brussels, 1986) p. IV-9, .

Concomitantly with these regional efforts, national programmes (mainly those in FRG and France) have been strengthened, aiming at modernizing industrial structures and creating capabilities in advanced materials R & D.

In general, the European posture regarding AMs then has been defensive and aimed at "making up for lost time". Cohendet et al, recognizing such a need and trying to analyse the reasons, conclude: **"For a very long time Europe played a leading role in materials research...It would be going too far to say today that Europe has been overtaken, but there is no doubt that it has allowed the US and Japan to steal a march on it in research into most of the materials with the highest expected growth rates between now and the end of the century...There are perhaps many reasons why Europe lags behind (such as dispersion of activities, lack of foresight, divide between research and industry etc), but it is clear that inertia due to tradition is one that merits emphasis".**[21]

In terms of AMs the European industrial strategy concentrates mainly on the development of polymers and new light metals and alloys.[22] It recognizes the need to link research, production and consumption, aiming at taking advantage of the strongest capabilities of the region. In this sense, the European formula to stimulate this area seems to concentrate on the strategy of linking the most promising European family of AMs (new polymers, given the competitive strength of its chemical industry and its research capabilities) with one of the most promising European industrial consumers of AMs (automobile industry)

4.4 - Other Countries

Other measures and countermeasures regarding the development and introduction of AMs, have been adopted by countries such as Canada, Australia, China, Brazil, South Korea and some other developing countries. Such policies were developed mainly after the second half of the 80s. Most of them are related to the need for a protective policy (mainly in the case of big traditional materials producers who feel threatened by the new advances) or to the perspective of taking advantages of an important transition period.

4 - Japanese Strategy Towards the Development of Advanced Materials

Since Japanese industry can be considered as more vulnerable than others to potential energy and materials supply curtailments and more sensitive to economies with these inputs (because of its almost total reliance on imports), the development of advanced materials has been among its highest R & D priorities, mainly from the 1970s onwards. In the 80s the development of AMs has become one of the three cornerstones of the Japanese industrial strategy, along with microelectronics and biotechnology.

21 Cohendet et al. (1988) p. 371

22 Lastres et al. (1988 b)

The most important feature of the Japanese policy towards the development of AMs seems to be that the measures adopted in that country are geared towards radically changing the patterns of production and consumption of materials. In other words, Japan is pursuing policies concentrating on discontinuity of traditional production of materials and emphasizing the linkages between materials production and new sectors such as information technology.

As we have seen, one of the major characteristics of Japanese strategy on AMs has been the national concern with the development of these materials and the promotion and improvement of technological strengths through long-term R & D programmes with very high rates of industrial participation. The long term policies adopted in Japan for the development of these materials and their precocious commercialization (with the purpose of changing traditional consumption habits and aiming at acquiring leadership in the area) reflect calculated objectives such as to build up capabilities regarding the establishment of a new pattern of international competition.

The main targets of the policies regarding the development of advanced materials in Japan have been:

. the inauguration of a new pattern of production and consumption of materials, minimizing national disadvantages (innovative activities to substitute for high-priced factor inputs) and, at the same time, maximizing internal advantages (innovative activities to explore capabilities built up in electronics, for instance);

. the aim of building completely synthetic materials, controlled at molecular and atomic level, to cater for a more and more specific and sophisticated demand (utilization-oriented research);

. the strong emphasis on fusion of materials science with other disciplines such as physics, electronics, chemistry and, mainly, biology;

. the objective of developing advanced materials related to IT sectors;

. the promotion of internal and international interactions;

. the attention to R & D, production, marketing and consumption of advanced materials within a conception of a system.

In general terms, the Japanese policy for the development of AMs can be divided into 2 phases. The first (adopted in the 70s), when advanced ceramics were chosen to be the basis of future industries. This choice was made according to two related factors. Firstly, the development of advanced ceramics, in the way it has been pursued, represents a major attempt to considerably reduce mineral and energy inputs (in terms of volume and price) in both production and utilization of materials. Secondly, it represents a very technology-intensive production and a more flexible production organization in a completely new area.

Many advanced ceramics are superior to traditional materials in various industrial applications, resulting in economies in materials and energy (such as applications in automotive engines, meaning lighter and more fuel efficient motor vehicles) as well as in products that cannot be made of conventional materials.

Ceramic materials are also generally more abundant and evenly distributed throughout the earth's crust than conventional metals. Alumina and silicon ceramic materials are plentiful even in Japan. Their refinement and downstream fabrication processes tend to require relatively less energy than metals, need not be located in congested areas and are more pollution-free.

On the other hand, one has to consider that the selection of ceramics to be the core of AMs plays an important role in terms of producing a discontinuity in materials production and consumption. The emphasis on new plastics, for instance, (and as pursued in the US and Europe) could be seen in Japan as a desired but much more difficult target, because of the strong international competition in chemical industry.

As we have seen, Japan has been emphasizing the improvement of advanced ceramics since the mid-70s. This issue did not lose priority within the main national targets, despite the expected technical/economic results in terms of structural ceramics until the mid-80s not having been entirely fulfilled. Due to this patient and long term public policy, Japan can now count on a large base of skill and experience in the field of ceramics, which is fundamental for the development of the programmes on high temperature ceramic superconductors. Such experience relates to previous activities in research, development, production, commercialization and use of ceramic materials.

Regarding this issue concerning superconductivity it has also to be mentioned the Japanese long term investments in the field of metallic superconductors. After the discovery of the new ceramic superconductors, in 1986/87, Japan had the advantage of having placed ceramics and superconductivity among the top priorities in its R & D programmes years before. Then, rapidly, these two priorities were linked to form a new programme oriented to exploit and augment the capabilities built up in both areas. In fact, one the most impressive Japanese features seems to be the agility with which public policy can be reoriented to the new discoveries and new perspectives of growth. Now, the concrete possibility of Japanese supremacy in the field of ceramic superconductors is so high that US measures under Reagan's administration concerning this subject have been considered as a response to this situation.[23]

The second phase is consistent with the new strategy, conceived in the late 80s, of creating new paths for the development of science and technology (and which relies on "Japanese creativity" and the development of international programmes for basic and fundamental research, such as the Human Frontier Programme).

In this new phase the intention emerges of developing advanced materials beyond the traditional concept of materials. For example, intelligent materials (a new substance or material which surpasses single-function

[23] See, for instance, Committee on Science, Engineering and Public Policy (1988) and UNIDO (1987).

materials and those which change function in response to changes in environmental conditions), which possess key functions such as self-recovery, self-adjustment or control, self-diagnosis, stand-by capabilities, self-reproducibility and ability to be externally tuned.[24]

6 - Impact of Advanced Materials

We saw in the previous sections that with the development and introduction of advanced materials, some important changes are expected to influence the way science and technology are developed and materials are produced and consumed. The policies adopted by different countries and firms (be they the most aggressive or the most complacent ones) reflect the intention to build up capabilities conforming to a new international pattern.

In the later two sections, I briefly discussed the advanced countries' posture toward AMs, for such countries are the ones which have better conditions for influencing and shaping this new pattern. Despite recognizing the importance of discussing the foreseen global impacts of the introduction of these materials in the international scenario, in this section I will focus on the impacts for the so-called Third World countries, for they seem to be the most dramatic. I will also use some examples from the Brazilian experience on advanced materials which I believe to be very interesting and which is the situation I know best.

As we saw, the introduction of AMs in the market has been accompanied by a decreasing trend in terms of the advanced countries consumption of raw and traditional materials. In global terms, the same sort of declining trend can be identified. The analysis of the world consumption of the seven major metals shows that their yearly rate of growth turned negative after 1979 (see Figure 9). The crisis that started in the early 70s put an end to the high rates of demand growth experienced by most major metals during the period of the 50s and 60s. This **slowdown** was further deepened by the recession which took place in the early 80s.

Such a change has various consequences for the less developed countries (LDCs), especially those which are important producers of traditional materials and ores. The most visible one refers to the expected negative impact on the balance of trade of these countries. According to Gonzalez-Vigil (1985): '**The significance of this fall is paramount indeed, as the seven metals** (analysed in Figure 9) **represent around three quarters of more or the value of all metals minerals in the world economy and, in particular, they accounted for three quarters of developing countries' exports of all non-fuel minerals in the mid-70s and together with manganese ore, for 53% of the total non-fuel mineral export earnings received by developing countries in 1980.**'[25]

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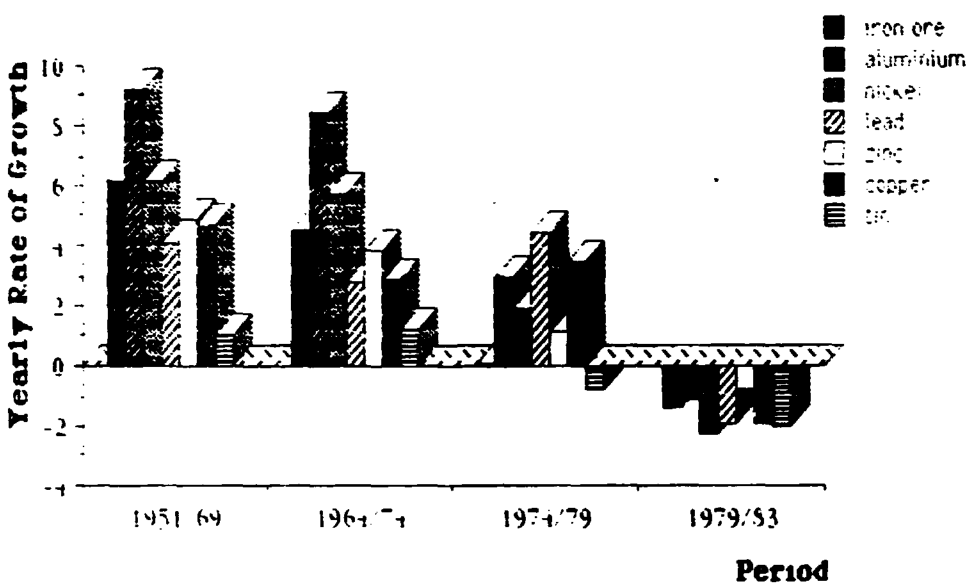
[24] Yanagida (1987) and Saito (1989).

[25] Gonzalez-Vigil (1985), p. 12.

Figure 9: Declining Trend in World Consumption of Major Metals



Source: Gonzalez-Vigil (1985)

It is worth mentioning that such a declining trend does not necessarily imply an absolute decline in the volume of raw material and metals exports from developing countries. But it does mean that the consumption of such products is no longer increasing at the same rate as it used to in the past. On the other hand, it is expected not to increase as much as the total increase in manufacturing output in the future.[26]

It is also expected that the metals industry's current international division of labour will continue for some time, but not for long. Developing countries are expected to be the fastest growing market for the major metal raw materials produced by themselves. Then, while in the past a greater rate of consumption of major metals used to express a greater level of industrial development within the different countries, today it has turned to be the opposite. Low consumption growth of metals is now considered a characteristic of mature developed economies.

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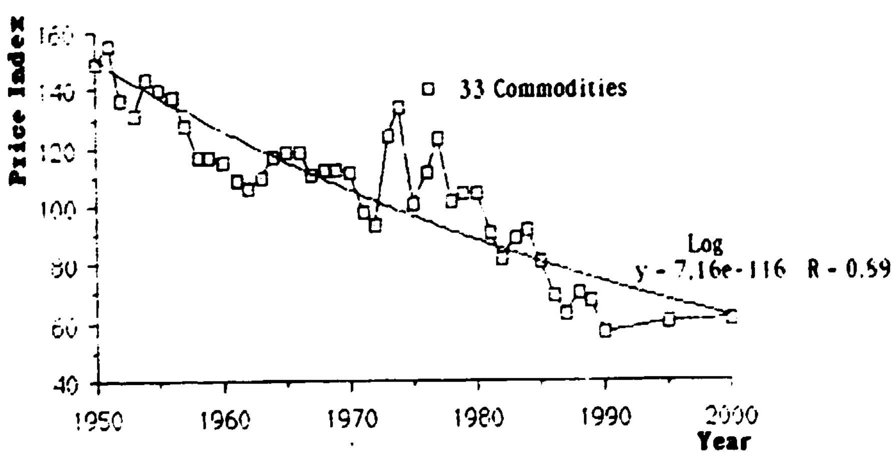
26 **See US Bureau of Mines (1988) and World Bank estimates.**

At the same time, figures about the estimated world market for AMs are eloquent showing growth rates around 20% per year. And if the traditional materials sector is losing its importance and separating more and more from the dynamic axis of industrial growth, worse than this is the depressing trend experienced by the prices of those traditional materials and raw materials .

In fact, as the World Bank has demonstrated, such a declining trend can be seen as the general tendency of commodity prices (excluding petroleum) in the last decades. Figure 10 shows the weighted index of prices for 33 non-fuel commodities in the period 1950/2000. This group of commodities includes agricultural products (67.7 %), minerals and metals (27.1%) and timber (5.2%).[27] It is clear from the figure that the price index of these commodities is experiencing a remarkable decline in the analysed period. It is worth emphasizing that these data also indicate that, after the 80s, short run price increases were always followed by greater price decreases.

As the price forecast reveals, non-fuel commodity prices are expected to decline even more from their 1988 level over this and the next year and are expected to make only a modest improvement over the 1900/2000 period, increasing only 5% with the price forecast for 2000 representing only 45% of the price at the beginning of the period.

Figure 10: Weighted Index of Commodity Prices
(Constant 1985 US Dollars)



Source: World Bank (1989)

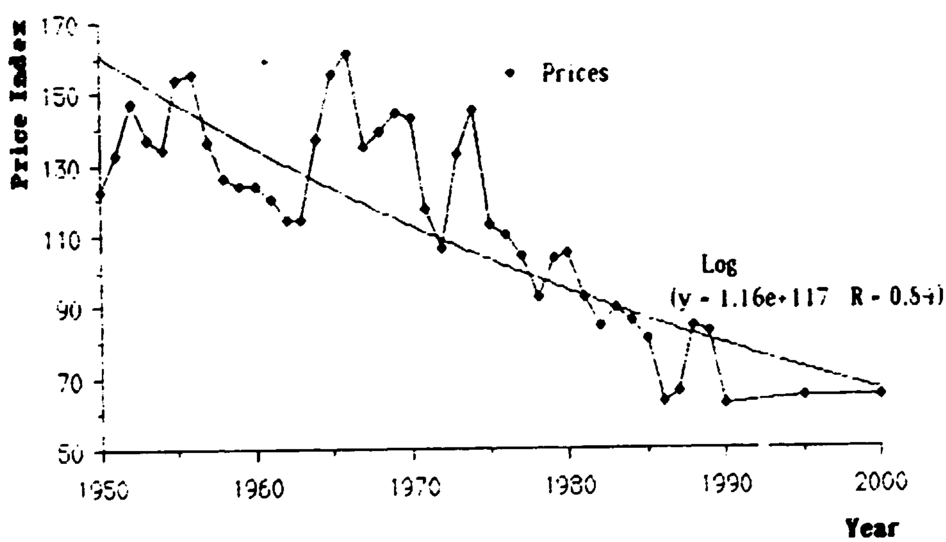
27 For the methodology used to produce these data see World Bank (1989)

Figure 11 shows the weighted index of metal and mineral prices for the same period. From it we notice the consistent decline in the prices of these products. Such a decline became sharper after the 70s.

The decline in minerals/metals prices expected between 1988 and 1990 is about 16%. An improvement of 10% is expected over the 1990/2000 period. As a result, the average metal and mineral prices index estimated by the World Bank for this decade (1990/2000) is less than half of the 50s and 60s averages.

Figure 11: Weighted Index of Metal and Mineral Prices

(Constant 1985 US Dollars)

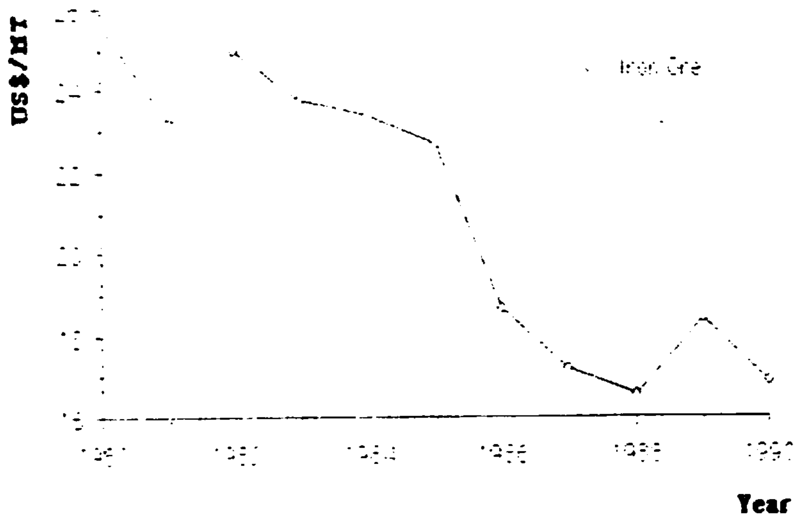


Source: World Bank (1989)

In terms of the analysis of specific price behaviour, the next figures present the trend for 4 selected ores and metals in the last decade.

Figure 12 shows the declining trend in the prices of iron ore. We can see from it that the prices of this ore fell from 25.6 US$/MT in 1980 to 16.6 US$/MT in 1988 and are estimated to reach 16.9 this year. It should be emphasized that in 1970 the price of iron ore was 41.8 US$/MT, i. e. 2,5 times the present price.

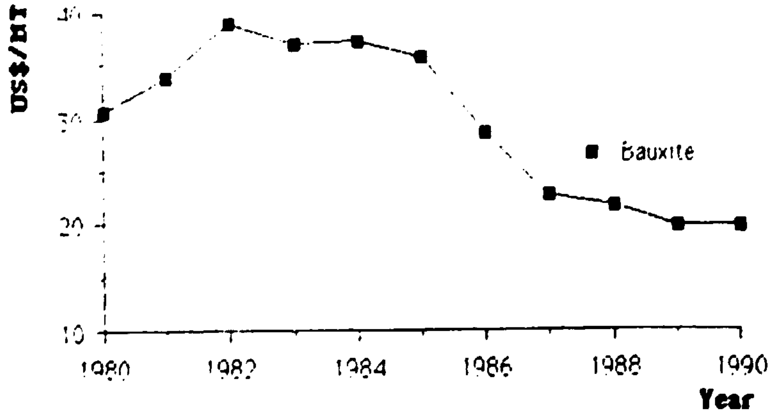
Figure 12: Declining Trend in Iron Ore Prices
(in 1985 constant US dollars)



Source: World Bank (1989)

Figure 13 shows a similar trend for the prices of bauxite in the same period. In this case, the price of bauxite, which reached 39.2 in 1982, experienced a fall of almost 50% during the following 6 years, reaching 21.8 US$/MT in 1988. The estimate of the World Bank shows that a continuing decline is expected this year, with the price falling to 19.8 US$/MT.

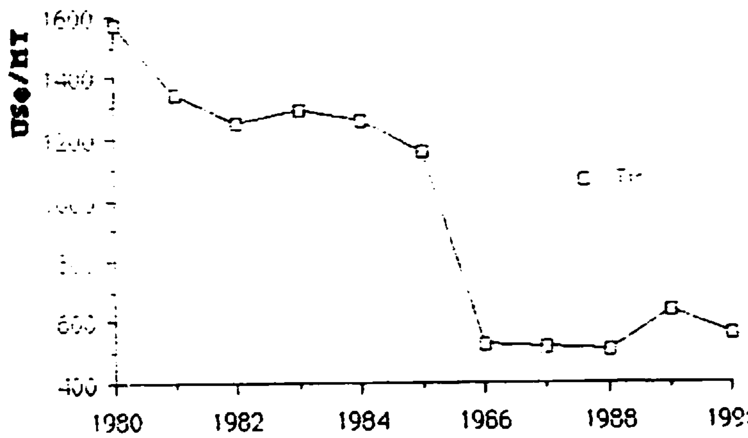
Figure 13: Declining Trend in Bauxite Prices
(in 1985 constant dollars)



Source: World Bank (1989)

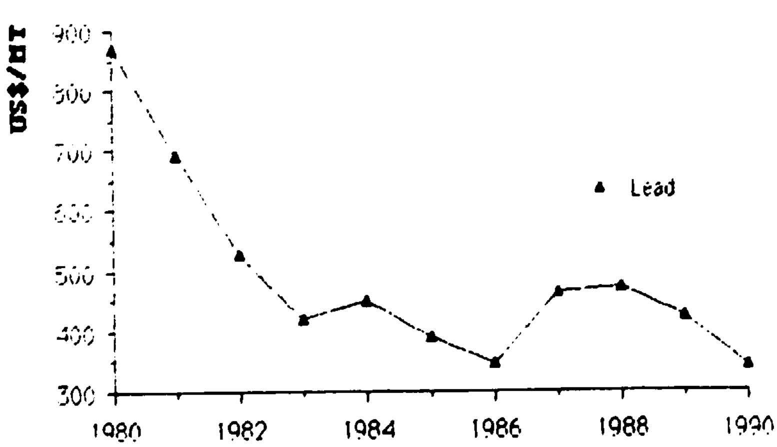
Among the metals, tin and lead were the ones that experienced the most dramatic price fall in the last decade, as Figure 14 and 15 show. From 1980 to 1988 tin price fell more than 300% and lead price almost 200%. In the latter case, a major decline is still expected. The estimated price of lead for this year represents almost one third of the price of 1980.

Figure 14: Declining Trend in Tin Prices
(in 1985 constant US dollars)



Source: Worl Bank (1989)

Figure 15: Declining Trend in Lead Prices
(in 1985 constant US dollars)



Source: World Bank (1989)

The impact of these changes on the metallurgy of developing countries will of course depend on the degree and pace of the dissemination of AMs. For most metal producers, even in advanced countries, their attempts to remain in the market and make profits in such a difficult scenario involve some very difficult options. But the discussion of the foreseen impacts of the introduction of AMs on LDCs, as well as the alternatives which can be open to these countries, transcends the limits of a simple change in the materials basis of the economy. The range of aspects that have to be discussed varies from the difficult financial situation of most the LDCs (and, in specific terms, of the metals producers in these countries [28]) to the specificity of AMs development and production (such as their sophisticated technological requirements and their interaction with and dependence on consumers).

Attempting to discuss some of such aspects, I would stress the fact that with the advent of advanced materials the tendency in materials production seems to be a complete change from production based on physical factors endowments, leading to an increasing dependence on sophisticated processes and resulting in an era of strong savings in energy and natural resources. As one result, the introduction of advanced materials is already changing (and is expected to lead to a dramatic major change) the structure of the so-called traditional comparative advantages and the present international division of labour.

Then, from some developing countries' point of view, these recent changes pose a perhaps unprecedented challenge and render much of the currently practised development strategies obsolete, mainly those based on production geared to exports of ores and basic metals. As we saw, a significant number of developing countries have had exports of minerals and basic metals as the core of their growth strategies. In 1985, among the LDCs which had more than 50% of their exports originating in the mineral sector, the cases of Zambia (94%), Bolivia (82%), Zaire (74%), Peru (70%), Jamaica (67%), Chile (64%), Togo (52%) and Papua New Guinea (51%) should be emphasized[29]. Even bigger countries which have implemented more sophisticated economic structures like Brazil and Australia have a significant share of their export revenues derived from mineral production.[30]

In this new situation, the importance of large and high grade national mineral reserves, relatively cheap and abundant energy inputs and non-qualified work (even with extremely low levels of wages) is tending to diminish. The consequences of such changes have to be analysed not only in terms of the threat to developing countries' international market share and export earnings, but also in terms of the loss of attractiveness this new situation exerts on foreign investments.

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28 Such a situation is worsened by the lack of agility that government bureaucracy and traditional materials producers may display when facing the challenge of restructuring.

29 World Bank (1987)

30 See Lastres & Cassiolato (1989).

The best example in this case is perhaps that which relates to the Carajas Project in Brazil. It was designed in the early eighties to attract foreign capital via exploitation of Latin America's most important mineral province in the Amazon. The Brazilian Government provided the necessary infrastructure for the project, including ports, railroads, energy supplies and various subsidies (ten year exemption of federal and regional taxes, energy prices below cost, etc.). Even with such subsidies the project failed as far as its main objective is concerned. Only the iron subproject led by a State company - CVRD - was implemented with the external participation of the World Bank and other minor foreign partners, leaving aside original subprojects for other minerals. The "failure" was due to lack of interest by foreign investors (both financial and productive firms) in investing in Brazil in minerals and basic metals. It is interesting to point out that the same model had been very successful throughout the sixties and the seventies.

One related implication here is the expected change in the location of materials production. Given the relatively lesser importance of the availability of inputs and the greater importance of the linkages with their consumers, the processing plants of advanced materials tend to be located near the consuming and end-using industrial markets. On the other hand, as most of these AMs are high in value and low in volume and weight, they are mostly economically transported by air. Hence, the emerging geographical pattern of advanced materials production is expected to be centred in those countries with better technological capabilities and strong markets for high-tech products. Given such expectations, some analysts of the area have concluded that the plants located in LDCs will tend to serve local and regional markets only.[31]

Apart from all the other macroeconomic problems faced by the developing countries (high external debt, accelerating inflation and political and institutional instability), and together with the uncertainty surrounding mainly minerals and basic metals (regarding the serious decline in demand, problems of supply overcapacity and depressed prices of ores and primary metals experienced during the 80s), it has to be considered that the traditional means of articulation between LDCs and the advanced countries are experiencing major changes.

Then, the main argument here is that these recent changes have lead to far more complex industrialization processes, where comparative advantages depend increasingly on innovation (both technical and organizational), rather than on purely physical factor endowment.

The high requirements of sophisticated scientific and technological knowledge the production of AMs implies can be seen as a handicap for those LDCs who intend to produce such materials. Brazil, for instance, has (in a very advantageous condition) all the important mineral resources needed to produce advanced ceramics, but, until 1988, there was no production of high purity ceramic oxides in Brazil. Even the most consumed ceramic oxide

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31 See Gregory (1988)

in the world, alumina, was not produced in that country with the purity required for its utilization in electronic devices[32] (even despite Brazil being one of the major world producers of alumina and aluminium for years). As a result Brazil exports the ores and oxides which are submitted to further purification and imports back the necessary inputs to produce those advanced ceramic which are processed in the country. The reasons for such a situation relate to the internal lack of sufficient technological capability to produce such pure oxides and the still small Brazilian advanced ceramics market.[33]

On the other hand, it is not only the fact of suddenly finding themselves producing "traditional materials" with "inputs and technology of the past" that matters in the case of LDCs. The shift to the production of AMs would also require a new industrial and sectoral organization, as we saw in section 3. Among all these requirements, I would particularly stress the more flexible and agile style of production and the linkage between research, production and consumption of materials. Many authors have emphasized such characteristics when discussing the new techno-economic paradigm and the new high-tech areas, much have expanded the understanding of the problem.[34] Regarding the latter, I would only repeat that the very genesis of such a new category of materials is a result of those linkages. In other words and as suggested in section 2 and 3, the advent of AMs is a result of the huge research and development programmes, particularly those in high-tech areas, pursued by governments and firms in the most advanced countries.

Having seen this, one could conclude that previous capabilities in traditional materials production has very little contribution to offer to those who aim at starting the production of advanced materials. In fact, as we saw in section 3, the international trend in terms of the production of AMs shows that the research-production-consumption relationship has prevailed over the traditional input-production linkages of the previous paradigm.

In the Brazilian case, which certainly follows the international trend, for instance, traditional materials producers have made very little effort to

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32 Lastres (1988 b). See specifically the section on advanced ceramics produced by Maria Thereza Garcia Duarte: "**Assim, apesar de dispormos de recursos minerais no Brasil em situação extremamente vantajosa, ainda não produzimos insumos na pureza e granulometria exigidas _ mesmo o óxido mais amplamente utilizado a nível mundial - a alumina - ainda não é produzida no país na pureza que permite sua utização em componentes eletrônicos**" (p. 49)

33 The survey produced on the Brazilian advanced materials sector, during 1987/88, showed that some big multinationals firms which were already investing in the country in other areas (and which started to produce advanced materials in their countries of origin) stated that they would wait for the Brazilian advanced materials market to grow before investing in this new area. One interesting discussion here would be that related to the applicability of the traditional concept of economies of scale to define a strategy related to the production of advanced materials.

34 Among them see various works by Freeman, Perez and Kaplinsky. On the importance of user/producer relations in shaping technical developments of new technologies see Lundvall (1985) and specifically in a developing country context, see Cassiolato (1990).

produce AMs. The most successful attempts to produce AMs refer to the cases of those firms which had the support of and have strong linkages with high-tech consumers (especially those in the information technology, aeronautics and defense sectors). It should also be emphasized that most of these cases relate to the constitution of a new firm formed by researchers and professors, mainly from physics and electronics institutes.[35]

A great commitment to the production of traditional materials by big firms and governments of LDCs can even retard the restructuring that the recent changes are forcing. In this sense, I would emphasize the necessity of a deep understanding of the present changes and the importance of sufficient agility and creativity by the public and private sectors to make the best of the opportunities that the beginning phase of a new paradigm presents.

In this aspect I fully agree with Perez, who argues that much of the knowledge required to enter a technology system in its early phase is in fact public knowledge available in universities, and that many of the skills required do not yet exist. Her conclusion is that, given the availability of well-qualified university personnel, a window of opportunity opens for the relatively autonomous entry of lagging countries into new products in a new technology system in these early phases."[36]

One example which shows the empirical validity of such theoretical contributions refers to the case of optical fibres in Brazil. The project was designed by the state company in charge of telecommunications - Telebrás - and matured into one the strongest university institutes which, since 1975, has been developing a research program on optical fibres together with Telebrás' research centre. In 1984 the technology developed earlier was transferred to a private national firm instituted to produce the fibres required for the development and renewal of the Brazilian telecommunications network. At that time an agreement was signed granting a 5-year market reserve by Telebrás (90% of the Brazilian market for optical fibre).[37]

One result of such measures is that Brazil is today one of the few countries in the world that holds an autonomous research program on optical fibres. In this case, I note that a modern and agile governmental institution could take the opportunity to articulate internal political interest in designing a strategic planning, promoting research-production-utilization linkages and making effective use of its active market procurement policy to build up capabilities in a high-tech area, which was new even in advanced countries.

Without any doubt the existence of a political and institutional framework was then (and continues to be) fundamental for the accomplishment of such a strategy. That seems to be of particular importance

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35 Lastres (1988 b)

36 Perez (p.92) Small countries

37 Lastres (1988 a), see especially the section on quartz and silicon by Cristina Lemos

especially in moments when a new technological trajectory is taking place. Freeman (1988) has strongly emphasized this aspect and has developed the idea of pervasive changes in technology associated with 'national systems of innovation' (the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies).[36]

Regarding the importance of designing specific policies which could exploit the temporary opportunities opened up by the new technologies, the Ministry of Science and Technology was created in Brazil in 1985. One of the main objectives of this Ministry was precisely to define and implement policies for high-tech areas.

In the specific case of advanced materials, a National Commission, a Centre for Studies and Planning and a Secretary were established in 1986 and 1987.[39]

As the main political and institutional alliances of the new government which took over in 1985 were not sustained, the measures regarding high-tech areas were gradually cast off. The friction with more conservative areas was so great that in 5 years the area had 4 ministers and in early 1989 the Ministry was dissolved and reestablished at the end of the year.

It should be recognized that the implementation of such policies (which require agility and deal with the renovation of the whole concept of national development) is a very difficult task, especially for LDCs that are facing great macroeconomic problems associated with political and institutional instability. But a definition of a new form of development can be considered fundamental, particularly for these LDCs, as they are now facing a crucial challenge related to their future chances of growth. Entering this new paradigm in its early phase and defining a national strategy to exploit the opportunities opened by the development of the new areas seems to present the best conditions for doing so.

In this sense, I emphasize again the primary importance of a better understanding of the specific characteristics of the development and introduction of AMs, particularly by the policy makers of LDCs. Some of the AMs. which are being introduced in these countries (mainly in sectors led by big multinational companies) contrast sharply with traditional policies pursued, particularly those which only emphasize the export of minerals and

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[35] "One of the most notable features of the Japanese system has been the speed with which Japanese firms and Japanese policy-makers _ identified the importance of information and communication technology (ICT) and embarked on measures to diffuse the new technology very rapidly to more traditional industries, such as machinery and vehicles. The Japanese system of technological forecasting is particularly well-suited to the identification, promotion and diffusion of major changes in 'technological paradigm' - pervasive technologies which can be applied throughout the economy." (pg 4/5)

[39] For a review of the Brazilian policy for advanced materials see article by J. E. Cassiolato, former Planning Secretary of the Ministry of Science and Technology and President of the National Commission for New Materials, published in the ATAS Bulletin (1988)

metals which, as we have seen, are experiencing a world-wide decrease in their consumption levels.

There is a strong tendency in these countries to follow the same steps as the most developed countries and accept high-tech advances as neutral and, in any circumstance, progressive ones. As a result, some of the LDCs are promoting the use of imported new materials which are displacing traditional materials they can produce (and for which they have inputs and technologies). In most cases this kind of behaviour consists in isolated attempts to reproduce some of the successful steps made abroad. There is no consideration of which kind of material would provide better results, regarding national conditions, and rarely is there any connection with policies adopted in other industrial sectors or those related to R & D.

Then, each country will have to use its best powers of creativity to define the most suitable policy and group of materials to which to give priority. This should be done regarding national conditions and constraints and selecting the most important policy tools and markets niches. Obviously the degree of agility and efficiency with which such measures are taken will eventually determine the level of success obtained.

Bibliography

The Association for the Progress of New Chemistry - Aspronc, Second International Symposium on New Chemistry: Expanding Frontier of Advanced Technologies - Action for the Age of New Chemistry, preprints (Tokyo, 24-25 Oct. 1989)

Brazil, 'O desafio dos Novos Materiais - Programa Brasileiro', Série Brasil Ciência nº2, MCT, Brasilia, 1987.

Cassiolato, J. E., 'Policies in Newly Industrialized Countries: the Case of Brazil' in Advanced Technologies Alert System Bulletin (5), UNO, 1988.

Cassiolato,J. E., 'Interaction User-Producer: Case-study of Banking Automation in Brazil', in H. Schmitz and J. Cassiolato (eds): High-Tech for Industrial Development, Institute of Development Studies, University Of Sussex, 1990, (forthcoming)

Cohendet et al. New Advanced Materials: Economic Dynamics and European Strategy, English version edited by M. Ledoux, 1988

Commission of the European Communities, Les Materiaux Nouveaux - Dynamique Economique et Stratégie Européenne, FAST Programme - FOP nº 146, Brussels, 1987.

Commission of the European Communities, Programme d'Action de Recherche - Materiaux 1986/89, Brussels, 1986.

Dosi, G. 'Technological Paradigms and Technological Trajectories' in Research Policy, 1982 11 (3).

Dosi, G., Technical Change and Industrial Transformation , Macmillan, London, 1984.

Duarte, M. T., 'Cerâmicas Avançadas - Diagnóstico do Segmento' in Lastres, H., Diagnóstico dos Novos Materiais, NMAT/INT/MCT, Rio de Janeiro, 1988.

Fasth, R. et al., 'Advanced Materials Markets' in Chemtech, July, 1988.

Forney, R. C., 'Advanced Materials and Technological Innovation' in Chemtech, March, 1988.

Freeman, C. Long Waves in the World Economy, (London 1984)

Freeman, C., Design, Innovation and Long Cycles in Economic Development (London 1986)

Freeman, C. Technology Policy and Economic Performance: Lessons from Japan, (University of Sussex, SPRU, 1988)

Freeman, C. and Lundvall, B., Small Countries Facing the Technological Revolution (London, 1988)

Forester, T. (ed.) The Materials Revolution: Superconductors, New Materials, and the Japanese Challenge (Oxford, 1988)

Gonzales-Vigil, F., 'New Technologies, Industrial Restructuring and Changing Patterns of Metal Consumption', Raw Materials Report 3(3), 1985.

Herrera, A., 'The New Technology and the Developing Countries: Problems and Options', in MacLeod, R. M., Technology and the Human Prospect: Essays in Honour of Christopher Freeman, Frances Pinter, London, 1986.

The International Technology Forum and The Engineering Academy of Japan, International Symposium on Advanced Materials and Issues of Science and Technology Policy (Tokyo, Oct. 1989)

Japan, Science and Technology Agency - STA, Promotion for Material Science and Technology Research and Development in STA (Tokyo, 1988)

Japan, Science and Technology Agency - STA, Research and Development Plan of the New Superconductors (Tokyo, 1988)

Japan, Science and Technology Agency - STA, Multi-Core Research Project on Superconductivity (Tokyo, 1988)

Japan, Science and Technology Agency - STA, Research Development Corporation of Japan Exploratory Research for Advanced Technology (Tokyo, 1988)

Japan, Science and Technology Agency - STA, White Paper on Science and Technology-1988 (Summary), Towards the Establishment of a New Creative Research Environment (Tokyo, 1988)

Japan, Science and Technology Agency - STA, STA, Its Role and Activities-1988 (Tokyo, 1989)

Japan, Science and Technology Agency - STA and Agency of Industrial Science and Technology - AIST/MITI, Human Frontier Science Program, Report of the International Scientific Committee (Tokyo, Jun. 1989)

Japan, Science and Technology Agency - STA and Agency of Industrial Science and Technology - AIST/MITI, Human Frontier Science Program, Report of the International Scientific Committee (Abstract) (Tokyo, Jul. 1989)

Japan, Ministry of International Trade and Industry - MITI, Agency of Industrial Science and Technology - AIST, 1988 Report - New Directions for Industrial Technology Policy (Tokyo 1988)

Japan External Trade Organization - JETRO,
JETRO News
The Japan Industrial and Technological Bulletin, special issue No 15, 1983 - 'The Development of Structural Fine Ceramics in Japan'.
The Japan Industrial and Technological Bulletin, special issue No 19, 1984 - 'New Metal Materials in Japan'
The Japan Industrial and Technological Bulletin, special issue No 19, 1984 - 'Special Polymer Materials in Japan'
Your Market in Japan, No 41, Mar. 1986 'New Materials'

Junne, G. et al. 'Dematerialization of Production: Impact on Raw Material Exports of Developing Countries' in Third World Quaterly, vol. 11, No 2, 1989.

Kaplinsky, R., Industrial Restructuring in LDCs: the Role of Information Technology, Stanford University, Stanford, 1988.

Lastres, H., Programa Grande Carajás: Aspectos Políticos e Institucionais, Rio de Janeiro, 1982.

Lastres, H., Novos Materiais: Capacitação e Potencialidades Nacionais em P&D , NMAT/INT/MCT, Rio de Janeiro, 1988.

Lastres, H., Diagnóstico dos Novos Materiais, NMAT/INT/MCT, Rio de Janeiro, 1988.

Lastres, H., Report on the II International Symposium on New Chemistry: Expanding Frontier of Advanced Technologies - Action for the Age of New Chemistry, University of Sussex, 1989

Lastres, H. & Cassiolato, J., 'High Technology Sectors and Developing Countries: the Case of Advanced Materials', Materials and Society, 1990 (forthcoming).

Lemos, C., 'Quartzo e Silício - Diagnóstico do Segmento' in Lastres, H., Diagnóstico dos Novos Materiais, NMAT/INT/MCT, Rio de Janeiro, 1988.

The Long-Term Credit Bank of Japan -LTCB
'Japan's High Technology Industries' in LTCB Research Special Issue, 3, Dec. 1984.

'Japanese Business Enterprises Diversification Strategies for the 1990s - Its Impacts on Corporate Profitability' in Monthly Economic Review, No 89 Nov. 1986.

Lundvall, B-Å, 'Product innovation and User-Producer Interaction', Industrial Development Research Series, n°31, Aalborg University Press, Denmark, 1985.

Morse, Research. A., International Competition and Cooperation on High Technology - the Critical Issues (Tokyo, Oct. 1989).

Neto, H. L. and Soares, M. C., 'Novos Materiais Metálicos - Diagnóstico do Segmento' in Lastres, H., Diagnóstico dos Novos Materiais, NMAT/INT/MCT, Rio de Janeiro, 1988.

Organization for Economic Development - OECD, New Materials (Countries Annexes), Paris, October 1988.

Organization for Economic Development - OECD, Le Politiques Nationales en Matiere de Materiaux Avances, Paris, October 1988.

Peiter, C. C. and Maldonado, J. 'Novos Polímeros - Diagnóstico do Segmento' in Lastres, H., Diagnóstico dos Novos Materiais, NMAT/INT/MCT, Rio de Janeiro, 1988.

Perez, C., 'Structural Change and the Assimilation of New Technologies' in The Economic and Social Systems, Futures, 1983, Vol. 15, n°5.

Perez, C., 'New Technologies and Development' in C. Freeman and B. Lundvall (eds.), Small Countries Facing the Technological Revolution , Pinter Publishers, London, 1983, p.92.

Perez, C. & Soete, L., 'Catching up technology: entry barriers and windows of opportunity' in G. Dosi et al. (eds.) Technical Change and Economic Theory, Pinter Publishers, London, 1988.

Perez, C., 'New Technologies and Development' in Freeman, C. and Lundvall, B., Small Countries Facing the Technological Revolution (London, 1988)

Pinhão, C. M., 'Materiais Compósitos - Diagnóstico do Segmento' in Lastres, H., Diagnóstico dos Novos Materiais, NMAT/INT/MCT, Rio de Janeiro, 1988.

Ray, G. 'Innovation in Materials' in R. MacLeod (ed.) Technology and the Human Prospect - Essays in Honour of Christopher Freeman, Frances Pinter, London, 1986.

The Royal Society Technology in the 1990s: The Promise of Advanced Materials, Cambridge 1987(includes Hondros, Marcum, Simenz, Barnes, Malpas, Chichos, Kröckel & Westbrook, Ashby, Kelly, Gilman, Schwattz, Phillips, Beldin & Staniland, Suzuki, Tan & Howard & Birchall).

Sá, P. C., Estratégias dos Grandes Grupos Internacionais no Domínio dos Novos Materiais, MCT, 1989.

Souza, Problems and Opportunities in Metals and Materials - an Integrated Perspective, U.S. Bureau of Mines, Washington, 1988.

UNIDO, 'High Temperature Superconductive Materials' in Advances in Materials Technology: Monitor, issue number 11(1987/4).

U.S. Congress, Office of Technology Assessment - OTA, New Structural Materials Technologies - Opportunities for the Use of Advanced Ceramics and Composites: a Technical Memorandum, Washington, 1986.

U.S. Congress, Office of Technology Assessment - OTA, Commercializing High-Temperature Superconductivity, OTA-ITE-388 Washington, June 1988.

U.S. National Research Council, Materials Science and Engineering for the 1990s - Maintaining Competitiveness in the Age of Materials (National Academy Press, 1989).

World Bank, Price Prospects for Major Commodities, 1988-2000, vol 1, Washington, 1989.

Yano Research Institute Ltd, Japan's Innovative Industrial Materials Tokyo, January, 1984.

Yano Research Institute Ltd, New Ceramics Market in Japan Tokyo, August 1982.