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ADVANCED MATERIALS TECHNOLOGY SERIES 1

Advanced Materials in High Technology and World Class Manufacturing

THE MATERIALS REVOLUTION AND THE CHALLENGE TO WORLD INDUSTRY IN THE 1990s

Prepared for UNIDO by Lakis C. Kaounides, City University Business School, London, United Kingdom.
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SCOPE AND DESCRIPTION

ADVANCED MATERIALS TECHNOLOGY SERIES is published in response to recent technical changes across virtually all high technology fields today, posed by the arrival of a generic and enabling technology, namely advanced materials and its accelerating assimilation and deployment. The materials sector has emerged as a science-based, knowledge-intensive high technology area with serious repercussions for technical change, competitiveness, growth, employment, trade patterns, location of manufacturing activities and the global division of labour. Technical change across virtually all present day high technology fields depends critically on advances in materials. Moreover, new materials development is an essential part of attempts to resolve the pressing environmental problems in mining, metallurgy, manufacturing and the global eco-system. The mastery and control of advanced materials technologies will lead to dominance in several high technology fields and major segments of manufacturing into the next century.

ADVANCED MATERIALS TECHNOLOGY SERIES is focused on the interest of policy makers in government departments, senior managers in industry and scientists who deal with materials issues and will assist them to identify the functions new and advanced materials have in industrial and economic competitiveness, and in formulating their strategies for the materials sector in their countries' industries.

ADVANCED MATERIALS TECHNOLOGY SERIES aims at encouraging the development of strategic orientation and business strategies in basic materials producing industries by providing a broad interdisciplinary platform for the presentation of new materials research, development and processing concepts and their increasing role in technological leadership and competitiveness.

ADVANCED MATERIALS TECHNOLOGY SERIES aims at covering the multidisciplinary nature of materials science and engineering and its transsectoral impact on major manufacturing industries in both developing and industrialized countries.

TOPICS COVERED

- Technical change in the 1990s and its dependence on materials science and engineering
- Science, technology and industrial competitiveness
- Industrial and technology policy
- Materials processing and manufacturing engineering
- Technological leadership and competitive advantage in the 1990s and in the next century

INTRODUCTORY NOTE TO THE SERIES

The present series of studies contains several findings which are of critical importance to strategic planning by senior management and government officials in several industries in both the developed and developing or newly industrialising economies (NIEs). In fact the trends identified herein pose a serious question mark for the competitive survival of major segments of manufacturing and high technology industries, located within specific national boundaries, into the next century. The series therefore constitutes a serious warning[1] to industry posed by the arrival of a generic and enabling technology, namely advanced materials, and its accelerating assimilation and deployment by industry. Developing economies must begin to offer a strategic response to the threat and opportunities afforded by the new technology to their traditional primary and manufacturing production and exports.

We are currently at the early but secure and irreversible stages of a remarkable and far-reaching materials revolution. The materials sector has emerged as a science-based, knowledge-intensive high technology area with serious repercussions for technical change, competitiveness, growth, employment, trade patterns, location of manufacturing activities and the global division of labour. Moreover, new materials development is an essential part of attempts to resolve the pressing environmental problems in mining, metallurgy, manufacturing and the global eco-system.

Advances in computer-aided instrumentation, modelling, experimentation, characterisation, testing and measurement technologies have, since at least the early 1980s, led to a revolution in the scientific and engineering knowledge base of materials research, design, processing and fabrication.

Materials scientists and engineers are now able to intervene at the electronic, atomic and molecular structure of matter, in order to both synthesise and process new materials possessing the desired microstructure and corresponding novel set of properties tailored for specific applications.

These breakthroughs in materials science and engineering (MSE) are having two consequences for the materials sector. Firstly, the new insights have permeated traditional and conventional materials leading to marked improvements in quality and processing technologies. Secondly, the transformations under way have spawned proliferating clusters of high-performance, knowledge-intensive new and advanced materials such as advanced metals, electronic and structural ceramics, high temperature superconducting materials, advanced composite and laminate systems and engineering polymers. Many of the new and advanced materials are tailored for end use applications in complex engineering systems in high-tech activities such as aerospace, where performance is more important than cost.

Nevertheless, the gradual resolution of processing constraints to higher volume low cost output, intense competitive pressures in the market place and the stringent performance requirements across increasingly sophisticated user industries are combining to facilitate ever greater diffusion of such materials across manufacturing industries. This is because the incorporation of new materials, in the context of simultaneous manufacture, into new products and processes confers several competitive advantages. These include higher performance characteristics, higher quality, and, opportunities for total system cost advantages in product design (or, redesign of an existing product), including manifold gains through the redesign of the manufacturing and assembly process. Many consumer goods, including cars, sporting goods (tennis rackets, golf clubs, bicycles, etc.) and industrial machinery are already incorporating advanced polymer matrix composites and advanced steels. Nearly half the new steels now used in cars were unavailable even six years ago.

Technical change across virtually all high technology fields today critically depends on advances in materials. For example, existing materials cannot meet the stringent technology requirements of the next generation electronic and photonic devices which necessitate even more highly advanced materials synthesis and processing technologies, novel instrumentation and measurement techniques and theoretical understanding of the quantum mechanical level. Consequently, further technical progress in such fields as information and communications, surface transportation, aerospace, deep sea operations, energy conversion and conservation, biocompatible materials, medical diagnostics, environmentally safe products and "clean" technologies, biotechnology and the life sciences, is materials constrained.

The mastery and control of advanced materials technologies will lead to dominance in several high technology fields and major segments of manufacturing into the next century. This view is best understood in Japan, at both the government and senior management level. Advanced materials programmes have been in place since the early 1980s in Japan. More recently advanced materials have been singled out as a national priority by Taiwan Province of Chine and the Republic of Korea as they shift to high technology by the year 2000. Brazil and India are also in the process of devising long run materials strategies. In the USA several commentators have identified advanced materials as the most important issue facing the economy in the 1990s. In response to the growing Japanese challenge in biotechnologies and advanced materials, the Bush Administration launched new initiatives in both fields in 1992. The emphasis on high technology received further impetus under the new Clinton Administration in 1993. Within Europe, the European Community (EC) has been pursuing the BRITE/EURAM programmes since the mid-1980s but doubts exist as to their effectiveness. The aim has been to pursue an intensive and sustained community-wide research programme in industrial and materials technologies in the context of providing the appropriate framework which would induce the private sector to undertake market oriented research and development. The Fourth Framework Programme (1994-1998) shows a distinct commercial orientation.

Today's MSE has emerged from its diverse scientific and engineering roots as multidisciplinary in nature and applicable across all classes of materials.

Synthesis and processing capabilities have emerged as the crucial determinants of achieving international leadership in materials over the next decade. Moreover, the possession of a minimum critical mass of domestic materials synthesis and processing competencies facilitates the fast transfer of new materials inventions into technological and commercial application.

The materials revolution is playing a determining role in the internal transformation, restructuring, strategic orientation and business strategies of firms in basic materials producing industries.

Over the last twenty years many firms in traditional industries such as steel, aluminium, copper, petrochemicals, chemicals, glass and ceramics have been reducing their dependence on commodity materials production while moving towards knowledge-intensive, higher value-added specialties and diversifying into new and advanced materials.

Traditional monomaterial chemical, metals and ceramic firms are evolving towards large, materials multinational corporations (MNCs), have been engaging in cross-border strategic alliances and are characterised by an emphasis on quality, flexibility, product differentiation and strong customer orientation. Getting close to the customer also involves the establishment of local production facilities and/or R&D and technical support centres.

Firms are beginning to acquire the necessary multidisciplinary and multimaterials competencies through the building up of internal basic and applied R&D capabilities. This is supplemented by external cross-border acquisitions (of specialty firms for example), joint ventures, R&D alliances, licensing agreements and technology networking and alliances.

Materials markets have been transformed in the 1990s. Markets are segmented by performance requirements and materials producers must provide a flexible and fast response to differentiated and ever increasing performance needs of end users. Successful firms must be able to offer complex engineering systems design tailored to customers needs.

Forces from the side of science, technology and new market conditions are acting so as to integrate materials producers and users in industry. The 1990s will witness an ever closer integration, indeed fusion, between the materials producing industries and the manufacturing sector.

The restructuring of basic industries is closely related to, and forms an integral part of the transformations under way in the manufacturing industry.

Firms must increasingly compete in a business environment characterised by globalisation of markets and production, and intensification of competition, faster product renewal, the emergence of quality and innovative design on par with price as determinants of consumer choice, the fragmentation of demand patterns, an increasing need to get closer to the customer, and the need for a flexible and fast response to market demand. Firms are responding by employing a range of new organisational tools (just in time (JIT), total quality management (TQM), total production management (TPM)) and microelectronics based automation technologies.

Design engineering has now been elevated to centre stage amongst business functions in today's market place. But more than this, the concept of concurrent engineering (or, simultaneous manufacture) has now emerged as the critical component in world class manufacturing. Here, R&D, and product and manufacturing design engineering are conducted in an integrated and simultaneous manner, together with inputs from marketing, accounting and suppliers.

Our analysis points to the important fact that new materials necessitate the redesign of both product and associated manufacturing process. In fact the materials, product and manufacturing process design must be done simultaneously. Therefore, far from being a passive element in a materials selection process, new materials mandate the adoption of simultaneous manufacture across industry and further reinforce the collaborative tendencies between materials suppliers and users. Further, the role of suppliers and equipment makers will become far more important in the 1990s and beyond.

The utilisation of new and advanced materials in the context of simultaneous manufacture is poised to provide the next major source of competitive advantage in world class manufacturing from the 1990s onwards.

The first study gives a clear understanding of interrelationships between advanced materials, technological leadership, competitive advantage and the challenge of the 1990s. Both governments and industry should have a very clear understanding of the role materials technology plays for a sustained competitive advantage and growth in the long run, and of the rising importance of advanced materials in the process of industrial restructuring.

The ensuing studies examine the origins, essential characteristics and consequences of the revolution in the science and engineering knowledge base of materials. They highlight the role of new materials developments in the context of the deep-rooted changes underway in the manufacturing industry. The studies look at emerging business strategies, which derive from on the one hand, the revolution in materials science and engineering, and on the other, the new manufacturing era. Clearly, strategic planning in the field of materials production and use must address itself to the competitive pressures of the new manufacturing era.

Having identified the broad trends underway in materials related industries, we then examine the central features, mechanisms and forms of the adjustment process in the economies of Japan, Malaysia, the Republic of Korea, Singapore, Taiwan Province of China and Thailand.

It is our hope that this series of studies will assist policy makers, industrialists and scientists who deal with materials issues, to identify the functions new and advanced materials have in industrial and economic competitiveness and in formulating their strategies for the materials sector sector in their countries' industries.

REFERENCE

1. The current recession and the potential for a slide into greater protectionism and generalised depression by the major economies ought not to deflect attention from the importance of the scientific and technological trends identified herein for long run innovation, competitiveness and growth. No Japanese company would discard R&D on fundamental core technologies deemed essential for long run growth, even in the face of adverse market and profitability conditions in the short to medium run. The tariff reductions agreed at the Tokyo G7 Summit in July 1993 and the resolution of the Uruguay Round of the GATT talks in December 1993, opened up the possibility of higher rates of growth and trade expansion in the coming years. Advanced materials, technological leadership, competitive advantage and the challenge from Japan and South East Asia in the 1990s.

PREFACE

Although much has been said about the role of materials science and engineering, which is considered to be multidisciplinary in its nature and transsectoral in its impact, in the economic development of a country a far more important issue has been evolving among senior managers – that of the critical and vitally important role new and advanced materials play in strategic planning for the competitive survival of major segments of manufacturing and high-technology industries into the next century.

On the basis of a comparison of internationally important key technologies and the present status and development trend in the sector of materials and processing technologies, it is already acknowledged throughout the world that materials technology, as the generic and key enabling technology, has significant and not inconsiderable importance as a basis for competitiveness in most industrial sectors. The further development and support of materials technology are so crucially important, precisely because very sizeable impetuses and spill-over effects on virtually all sectors of the processing industries result from them.

In future, both the new and advanced materials and those with improved properties will play an essential role in the development of such advanced technologies as electronics, mechatronics, new energy, aerospace, etc. At the close of the twentieth century, materials engineering, of all the key technologies, is the one with the greatest degree of interlinkage with other engineering fields and with the highest degree of positive external effects. However, this means that the independent development of materials is not profitable enough and can only be considered economically promising when viewed in association with subsequent systems activities and advanced processing methods.

For this reason, any future programme for materials and systems innovation should concentrate on *foci* in which the system's function depends to a great extent on the properties of the materials, and simultaneously assumes a key role in the competitive position of a country. For example, these include:

- Energy engineering
- Transportation design
- Information and communication technology
- Microelectronic systems
- Optoelectronic systems
- Medical engineering

The technological impact of new materials on related industries will be very significant, and this is a very important point. Because of their central importance for the future development of many sectors, materials and processing technologies are viewed internationally as being particularly future-oriented technology sectors. It is imperative to safeguard and develop the position achieved in this broad-spectrum sector of technology to fully exploit the potential for differentiation in internationally important and attractive sectors and thereby permanently enhance the competitiveness of a country's industry and companies in the world's markets.

The developments in the materials field also have serious implications for all developing economies, despite the fact that many them depend on primary commodity exports for their foreign exchange earnings. The United Nations Industrial Development Organization (UNIDO), has therefore been especially active in this area in the last decade by promoting the rational use of new materials and building-up/strengthening technological capacity in developing countries in the area of materials design, manufacturing and application.

One of the most important objectives of the UNIDO Programme on Technological Advances is to increase awareness through monitoring and assessing trends in new and advanced materials, by identifying problems faced by developing countries at a very early stage, and where relevant, to advise on and promote necessary actions for their solution.

As a part of this promotional programme, UNIDO has begun publishing a new series of studies entitled **Advanced Materials Series**, commissioned to monitor recent trends in materials science and engineering and to emphasize the determining role this discipline plays in the internal transformation, restructuring, strategic orientation and business strategies of the companies involved in basic materials producing industries

The first study gives a clear understanding of interrelationships between advanced materials, technological leadership, competitive advantage and the challenge of the 1990s, for which we are indebted to Lakis C. Kaounides of the City University Business School, London (UK). Both governments and industry should have a very clear understanding of the role materials technology plays for a sustained competitive advantage and growth in the long run, and of the rising importance of advanced materials in the process of industrial restructuring. The new series will be addressed to policy makers, industrialists and scientists who have dealings with materials issues and will assist them to identify the functions new and advanced materials have in industrial and economic competitiveness and in formulating their strategies for the materials sector in their countires' industries.

Investment and Technology Promotion Division
United Nations Industrial Development Organization

LIST OF ACRONYMS

AER	Japan Atomic Energy Research Institute
AES	Auger electron spectroscopy
AIST	Agency of Industrial Science and Technology
AMPP	Advanced Materials and Processing Programme
ARPA	Advanced Research Projects Agency
AST	Agency of Science and Technology
ASTM	American Society for Testing and Standards
ATM	Asynchronous transfer mode
ATP	Advanced Technology Programme
CAD	Computer aided design
CAM	Computer aided manufacturing
C/C	Carbon/carbon
CEC	Consulting Engineers Council
CIM	Computer integrated manufacture
CMC	Ceramic matrix composites
CRADA	Cooperative Research & Development Agreements
CTC	Civilian Technology Corporation
DARPA	Defense Advanced Projects Agency
DOC	Department of Commerce (National Institute of Standards and Technology, NIST)
DoD	Department of Defense
DOE	Department of Energy
DOI	Department of Interior
DOT	Department of Transportation
DRAM	Dynamic random access memory
EADI	European Association of Developmental Research and Training Institutions
EC	European Community
EFTA	European Free Trade Area
EOI	Export oriented industrialization
ERATO	Exploratory Research for Advanced Technology
EPA	Environmental Protection Agency

FCCSET	Federal Coordinating Council for Science, Engineering and Technology
GDP	Gross domestic product
GNP	Gross national product
HDTV	High definition television
HFSP	Human Frontier Science Project
HHS	Department of Health and Human Services
HIPs	Hot isostatic presses
HST	Hypersonic systems
IAC	Industrially advanced countries
IC	Integrated circuit
ICGEB	International Centre for Genetic Engineering and Biotechnology
IMAAC	International Materials Assessment and Applications Centre
IMF	International Monetary Fund
IMS	Intelligent manufacturing system
ISDN	Integrated services digital networks
JIT	Just in time
JISEDAI	Research and Development Programme on Basic Technologies for Future Industries
ITRI	Industrial Technology Research Institute
KAITECH	Korean Academy of Industrial Technology
KIST	Korean Institute for Science and Technology
LCF	Low cycle fatigue
LDP	Liberal Democratic Party
MIT	Massachusetts Institute of Technology
MITI	Ministry for International Trade and Industry
MNCs	Multinational corporations
MRL	Materials research laboratories
MSE	Materials science and engineering
NASA	National Aeronautics and Space Agency
NPL	National Physics Laboratory
NEDO	New Energy and Industrial Technology Development Organisation
NIEs	Newly industrialising economies
NIH	National Institutes of Health
NIST	National Institute of Standards and Technology
NRC	National Research Council

NRIM	National Research Institute for Materials
NSF	National Science Foundation
NSTB	National Science and Technology Board
OECD	Organisation for Economic Cooperation and Development
PEC	Petroleum Energy Centre
PMC	Permanently manned capability
R&D	Research and development
SC	Steering Committee
SDP	Sputter depth profiling
SEMATECH	Semiconductor manufacturers association (USA)
SIMS	Secondary ion mass spectroscopy
SOR	Spring-8 (Japan)
SPRU	Science Policy Research Unit
SSC	Superconducting super collider
SST	Supersonic transport systems
STA	Science and Technology Agency
TPM	Total production management
TQM	Total quality management
TWA	Technical working area
ULSI	Ultra largescale integration
UNCTAD	United Nations Conference on Trade and Development
UNCTC	United Nations on Transnational Corporations
UNCSTD	United Nations Centre for Science and Technology
UNIDO	United Nations Industrial Development Organization
USDA	United States Department of Administration
VAMAS	Versailles Project on Advanced Materials and Standards
VCR	Video cassette recorder
VLSI	Very large scale integration
XPS	X-ray photoelectron spectroscopy

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ADVANCED MATERIALS, NEW MANUFACTURING TECHNOLOGIES AND GLOBAL COMPETITIVE ADVANTAGE IN THE 1990s

1. INTRODUCTION

The materials revolution: the new manufacturing and the challenge to world industry in the 1990s

In this study we examine the main characteristics, trends and global industrial and economic ramifications of the development and diffusion of advanced materials technologies. However, it would be wrong to focus merely on matters relating to the specifics of the technology *per se*. Rather, a better understanding of the factors at work would need to incorporate the transformations under way in world industry and business. The analysis therefore brings together and integrates for the first time the scientific, technological and new manufacturing conditions under which industry operates and competes in the 1990s. The insights and conclusions so obtained therefore concern senior government officials and managers of public and private corporations and research institutes across the industrialised and industrialising world.

World industry has been undergoing a fundamental restructuring over the last two decades. The mass production paradigm developed by Henry Ford, Frederick Taylor and Alfred Sloan in the early part of this century has dominated industrial organisation for most of the post-war period but has now been rendered virtually obsolete. Lean production[4], almost the exact antithesis of mass production, is emerging as a new best-practice manufacturing paradigm slowly diffusing across industry, providing the foundations for sustained competitive advantage by world class companies in today's market conditions.

From the early 1980s three major new generic technologies have emerged to further complicate the process of industrial restructuring and global redivision of labour, the sources of competitive advantage, innovation, growth, the spatial location of primary and tertiary activities and prospects for export orientated industrialisation (EOI) across the developing economies, placing much of the traditional development theory and policy related propositions and modes of thinking in need of urgent reevaluation. Moreover strong evidence[5] suggests a rapid growth in the internationalisation of R&D activities and the formation of an increasing number and widening complexity, of domestic and cross-border R&D and technology alliances in the core technologies of information technologies, biotechnologies and advanced materials. These developments reflect the increasing costs and risks of R&D in high technology[6], the complexity and speed of change in frontier science and technology, the need to combine complementary firm-specific assets and synergy across a range of disciplines and technologies. Cross-border collaboration may indeed be an essential component of the innovation process today, providing for greater economic efficiency and global R&D spillovers. On the other hand, it might lead to the formation of oligopolistic or monopolistic market structures and socially detrimental market power exercised by the co-operating firms on a national or global level. These considerations further highlight the fact that policy formation seriously lags behind the advances in science and technology in the last 10-15 years. For example, much of the competition policy in place in many countries still views any form of collaboration between firms with strong suspicion. Yet collaboration in pre-competitive R&D, and possibly in near-market research or production and marketing, may be a prerequisite for development and commercialisation of new technologies. And, where alliances in specific areas of pre-competitive R&D are beginning to be encouraged (as in the USA, for example), a conflict can arise between the promotion of domestic alliances and the implementation of an industrial policy with the aim of supporting domestic high technology, which leads to the exclusion of foreign firms with potentially adverse consequences for innovation at home and abroad. Furthermore, the strong support provided by governments to high technology sectors together with the internationalisation of production and rising economic interdependence of nations, has meant that trade and technology issues are today inextricably linked[7]. Indeed, high technology increasingly provides the major source of trade friction and conflict[8] between nations and economic regions. In the absence of a multilateral framework for dealing with these issues at a global level, governments increasingly resort to unilateral industrial and trade measures to support, maintain or create competitive advantage for domestic branches of industry.

What ought, therefore, to be the appropriate policy response by developing, newly industrialising and industrialised countries to the new scientific, technological, industrial and business conditions? And, given the application of a strong 'visible hand' to high technology sectors in several economies, especially in the Far East, what are the realistic policy options open to competing economies? Is there an overwhelming case, indeed need, for the formulation of a long run strategic response[9] by both government and industry to the emerging scientific and technological conditions? If so, what factors would comprise such a response? Has the need for an 'industrial' or 'technology' policy acquired a new rationale and new urgency in the 1990s? What are the dangers of a serious misallocation and waste of economic resources in attempting to channel resources to specific industries at the expense of others? Would benefits outweigh losses? Can market forces be relied upon to provide an adequate, let alone socially optimal, rate of basic and applied scientific research, technology development and commercialisation? Indeed what are the scientific, technological, institutional, fiscal and legal framework requirements for invention, innovation, competitiveness and growth in high technology industries today? Hence, what is the proper domain of government intervention? Is the provision of a minimum critical mass of scientific and technological infrastructure the clear and indisputable jurisdiction of the state? Does the proper balance between the state and the market vary, or ought to vary according to the stage of socio-economic and institutional development of the economy concerned? What is the role of international organisations such as the United Nations Industrial Development Organization (UNIDO), the United Nations Conference on Trade and Development (UNCTAD), the United Nations Centre for Science and Technology (UNCST), the United Nations Centre for Transnational Corporations (UNCTC), the World Bank, the International Monetary Fund (IMF), the Organisation for Economic Co-operation and Development (OECD) and so on in this respect? The present study provides but an initial step in an attempt to understand the trends and forces at work and, thereby, provide essential inputs to national and international policy formation[10].

What is clear is that the materials sector today has evolved into a science-based, knowledge intensive generic and enabling high technology sector upon which all other technologies depend. The evidence, much of it assembled through numerous high level meetings in the economies of Japan, the Republic of Korea, Taiwan Province of China, Singapore, Malaysia and Thailand, provides many lessons, many opportunities and contains serious implications for government and industry outside this, the most dynamic region of the world economy in the 1990s.

2. THE MATERIALS REVOLUTION

A major new generic and enabling technology

2.1 The onset of advanced materials

We are currently at the early but secure and irreversible stages of a remarkable and far-reaching materials revolution. It constitutes a break from past experience and practice, in which monolithic materials entered final goods after some elementary transformation and manipulation of little understood microstructure. Since at least the early 1980s we have witnessed radical breakthroughs in the ability of materials scientists and engineers to both synthesise and process new materials so as to obtain the desired microstructure and corresponding novel set of properties and performance in use. The revolution in the science and engineering knowledge base of materials research, design and fabrication is having two major consequences for the materials sector. Firstly, the insights have permeated traditional materials leading to marked improvements in quality and processing techniques. Secondly, the transformations underway have spawned proliferating clusters of high-performance, knowledge-intensive advanced materials, such as engineering polymers, advanced metals, electronic and structural ceramics and advanced composite systems. New advanced materials, such as the aluminium-lithium alloys or carbon-carbon composites, are designed and tailored to meet specific end-use applications in complex engineering systems in high-tech activities, such as aerospace, where performance is more important than cost. Nevertheless, the gradual resolution of processing constraints to higher volume lower cost output, intense competitive pressures in the market place and the stringent performance requirements across increasingly sophisticated user industries are combining to facilitate ever greater diffusion of such materials in manufacturing.

The incorporation of new materials, in the context of integrated or simultaneous manufacture, into new products and processes confers higher performance characteristics, enhances quality and provides design (or redesign of existing product), total system cost advantages, including manifold gains though the redesign of the manufacturing and assembly process. Many consumer durables, including cars, sporting goods and industrial machinery are increasingly[11] falling prey to the irreversible, albeit slow and uneven, march of new materials across industry. Steel developments, for example, in recent years are a result of advancing frontier knowledge in MSE. A whole range of advanced steels with improved strength, corrosion resistance and ease of styling (formability), with precisely controlled chemistry and microstructure are customised for applications in cars, high-tech buildings and deep sea exploration. Breakthroughs[12] in steel design and processing methods are resulting in a range of high strength low alloy steels, bake hardening steels, ultraclean steels and advanced coated steels, which are enabling automotive engineers to improve performance, style, comfort, cost efficiency, manufacturing automation and flexibility and recyclability in car design and production. Nearly half of the new steels now used in cars were not available even six years ago. And today's new generation of advanced multilayer coating systems and technologies enable engineers to custom design protection for the surface and underside of the car's body. Ten years ago only 10 per cent of car bodies contained metallic coated corrosion resistance steels. It is predicted that by the mid-1990s, most new cars in the USA, Europe and Japan will be using them in 60 to 100 per cent of car bodies.

2.2 Technical change in the 1990s depends on materials science and engineering

Technical change across virtually every major field today depends critically on advances in materials. Existing conventional materials cannot meet the emerging requirements of high technology applications, as for example, in the next generation of electronic and photonic devices, which necessitate even more highly advanced materials synthesis and processing technologies, novel instrumentation and measurement techniques, and theoretical understanding of the quantum mechanical level. Thus, further technical progress in information and communications, surface transportation, aerospace, deep sea operations, energy conversion and conservation, biocompatible materials and medical diagnostics, environmentally safe products and 'clean' technologies, biotechnology and the life sciences, is materials constrained. Materials science and engineering (MSE) as a unified multi-disciplinary field engaged in the development of new materials in possession of extraordinary properties and tailored for specific applications, underpins every major technological advance, and thereby the ability to meet the competitive challenge in the market place, a broad range of socio-economic and environmental objectives and military security needs. Over the last decade or so, MSE has been elevated[13] to a unique, critical and central position in the functioning and growth of industrialised and industrialising economies. In short, **the age of advanced materials has arrived and is here to stay.** It is not widely recognised, that the materials sector today has emerged as a science-based, high technology sector in its own right, of critical importance to a vast array of downstream high-tech and manufacturing industries.

3. BASIC SCIENCE, NEW TECHNOLOGIES AND INDUSTRIAL COMPETITIVENESS

3.1 Basic science underpins new technologies in a complex two-way process

More than at any time before, the basic sciences today are responsible for major technological breakthroughs and the provision of the knowledge-base underpinning technical advance. Support for basic and applied scientific research[14] has therefore become a critical policy variable in debates over strategies to sustain technological leadership and devise appropriate industrial policies In recognition of this fact and the emerging Japanese challenge in high technology, the Bush Administration raised the USA's science budget request by 7 per cent to US$ 13.4 billion (Table 1) and launched new initiatives in advanced

Table 1: USA SCIENCE BUDGET

(figures in US$ millions)

	1992 enacted ($)	1993 Proposed ($)	% increase
BASIC RESEARCH			
Doubling the NSF budget by 1994	2,572	3,026	18
Support for individual investigators (NIH, NSF, DOE)	7,273	7,939	9
Human Genome Project	164	175	7
Superconducting Super Collider	484	650	34
Global Climate Change	1,110	1.372	24
Astronomy amd Astrophysics	836	890	6
Competitive agricultural research	96	150	53
APPLIED RESEARCH			
High Performance Computing and Communications	655	803	23
Advanced Materials and Processing	1,659	1,821	10
Biotechnology	3,759	4,030	7
Energy R&D	774	914	18
Fusion	337	360	7
Advanced Manufacturing	252	321	27
Public Health	4,757	4,849	2
National Institute of Standards and Technology	247	311	26
Space Technology	273	305	12

Source: **Nature**, 1992.

materials and biotechnology. The latter received $4.03 billion in response to Japanese targeting of the industry in a process reminiscent of the earlier successful targeting of semiconductors. Despite the decline in defense spending, the traditional 60:40 ratio of defence:civilian R&D spending only changed to 59:41 in the proposals, viewed as insufficient to fuel R&D for economic growth by the House Science, Space and Technology Committee. Nevertheless, the USA's science budget proposals indicate a distinct emphasis on the commercial application of research. This has been echoed[15] recently by Dr. Press, president of the National Academy of Sciences, who stressed that the USA is entering a new era and new impetus for the support of science. Relevance to defense is now being replaced by commercial relevance as an intrinsic feature of most science. Biotechnology industries exemplify the shift towards a new paradigm into the 21st century, whereby basic science provides the foundations of successful industry and is rapidly translated into commercial products.

Although the linear model of technological change, whereby invention inevitably leads to innovation which is then followed by diffusion, is now recognised to be invalid, recent studies confirm that basic research remains crucially important. However, the links between basic research and technological change are complex and multidimensional, including both written information and knowledge, technology management, skills, instruments and professional contacts which facilitate the tackling and resolution of complex technological problems. Applied science interacts continually with industry at each stage of the development of new market driven innovations and successive generations of new technologies, as for example, in the evolution of next computers. Mastery of current generations technology facilitates the development of next generations of the same or related technologies.

At the same time the introduction of a new product or manufacturing technique, does not automatically secure competitive advantage in the market place. The latter is a result of a process of continuous improvement, effective marketing strategy, good customer response, quality of workforce and management and company-wide innovation culture. Importantly, innovation and competitive advantage are greatly influenced by government industry-science relations and interactions within the national system of innovation. The proposition that what governments ought to do is simply to "get the science base right" and that new discoveries and inventions would inevitably or miraculously be translated into innovations and manufacturing advantages is grossly misleading today.

The new Clinton Administration is explicitly giving priority to "civilian" research and wants to reverse the 60.40 ratio in defense and civilian R&D expenditures, or at least balance it. Here, the process will be supplemented by mechanisms which facilitate a much faster transfer of defense technology into civilian industries, such as mixed consortia comprising of defense/Pentagon and private firms. Moreover, research conducted at Federal laboratories will be encouraged to flow to private industry in a range of initiatives and programmes in advanced materials (including super-conductors, advanced composites), ozone friendly refrigeration products, "clean" vehicle technologies, energy conservation

TABLE 2: FISCAL YEAR 1993 AMPP R&D FUNDING BY MATERIALS CLASS AND AGENCY

(US$ Millions)

Material class	DOC	DOD	DOE	DOI	DOT	EPA	HHS	NASA	NSF	USDA	Total[1]
Bio/biomolecular materials	0.2	19.6	2.5	-	0.1	-	81.7	4.0	23.0	56.3	187.4
Ceramic	5.8	22.4	90.6	2.1	-	0.8	-	1.3	19.5	-	150.5
Composites	4.0	86.1	29.5	0.9	2.44	-	-	69.9	12.1	1.1	206.8
Electronics	6.1	58.5	43.8	-	-	0.3	-	12.2	55.0	-	176.7
Magnetic	1.2	2.0	8.5	-	28.1	-	38.7	1.3	14.7	-	27.7
Metals	9.0	36.1	122.9	5.1	3.8	0.4	-	18.7	33.0	-	228.9
Optical/photonic	0.8	71.9	28.1	-	-	-	-	5.2	32.7	-	138.8
Polymers	5.1	23.1	20.4	-	-	0.5	-	12.6	22.9	8.7	93.2
Superconducting	3.2	68.5	38.7	-	0.1	-	-	5.4	26.9	-	142.9
Total: specific materials R&D[1]	35.4	388.2	384.9	8.1	6.4	2.0	81.7	138.7	241.5	66.1	1,352.9
Other non-specific R&D	12.6	43.7	293.0	15.8	9.1	2.5	-	14.8	77.0	-	468.5
Total materials R&D[1]	48.0	431.9	677.9	23.8	15.5	4.5	81.7	153.5	318.5	66.1	1,821.4

DOC – US Department of Commerce (National Institute of Standards and Technology);
DOD – US Department of Defence;
DOE – US Department of Energy;
DOI – US Department of the Interior;
DOT – US Department of Transportation;
EPA – Environmental Protection Agency;
HHS/NIH – USDepartment of Health and Human Services (National Institutes of Health);
NASA – National Aeronautics and Space Agency;
USDA – United States Department of Administration;
NSF – National Science Foundation.

[1] Data may not add to totals shown due to rounding.

Source: Committee on Materials, Office of Science and Technology Policy, Executive Office of the President.

and renewable energy.

In order to stimulate investment outlays to the order of US$ 100 billion between 1994-1997, tax incentives are offered to companies engaged in research, enabling them to write-off $6 billion in taxes. In an effort to further boost the USA's industrial R&D, especially in small companies, the President is aiming to more than quadruple the budget of the National Institute of Standards and Technology to $1.11 billion by 1997. The aim is to expand the Advanced Technology Programme (and its research grant capacity) of the NIST so as to make a substantive impact on the USA's industrial competitiveness. It is estimated that if the USA spends $150 billion annually on R&D, then a Federal stimulus of 0.5 per cent ($750 million) is required. These aims of the Administration to reorientate and boost the USA's research effort are, however, facing serious obstacles in Congress. President Clinton's and Vice-President Gore's technology policy is discussed further below (see inset in 3.3). Several initiatives are underway in the USA today, following on from the previous administration, including a strong emphasis on advanced materials R&D and processing technologies, as a result of important studies and conclusions reached by the US National Research Council and other federal agencies in 1989 and 1991. These continue to have the support of the Clinton Administration.

The critical importance of materials synthesis and processing is stressed in the important report by the National Research Council, Materials Science and Engineering for the 1990s, published in 1989. This theme was echoed in the follow-up report of the Materials Research Society[16], which evaluates the progress and requirements of implementing the Research Council's recommendations. The report makes the important, and somewhat surprising in the USA context, point that the USA now needs to move towards developing a "strategic, goal orientated planning approach to materials R&D, involving industry, universities and government laboratories".

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

- the need to enhance materials R&D activities, especially in synthesis and processing;
- the need to bridge the gap between basic understanding of materials and their technological applications; and
- the need to involve industry, academia, and the government in mission-orientated planning and the extension of R&D activities.

In order to address the identified opportunities and needs, a multi-year, multi-agency programme is beginning in FY 1993 in order to enhance the effectiveness of the Federal R&D Programme in Materials Science and Technology. The aim of the AMPP programme is to improve the manufacture and performance of materials, to enhance the nation's quality,

TABLE 3: JAPAN'S SCIENCE AND TECHNOLOGY BUDGET 1992

	Thousand million Yen	% change from 1991
Total R&D budget	259.7	+1.5
Japan Key Technology Centre	26.0*	-9.7
Basic technologies for future industries	8.2	+5.6
Large-scale industrial projects	14.7	+4.8
Sunshine new energy sources project	26.5	+8.6
Moonlight energy-saving project	11.8	+4.7
Fifth generation computer	3.6	-49.7
Sixth generation computer	0.9	+842.7
Global environment	8.2	+22.1
Intelligent Manufacturing System (IMS) project	0.8	+197.8
Human Frontier Science Project (HFSP)	3.8**	+3.5
Elucidation of biological functions (domestic HFSP)	0.3	-12.8
NEDO international grants	0.7	+53.4
Reorganisation of Tsukuba Science Institutes	14.9	+11.3
* Budget shared with Ministry of Posts and Telecommunications ** Budget shared with Science and Technology Agency		
Science and Technology Agency Budget for 1992	**Thousand million Yen**	**% change from 1991**
Total R&D budget	551.8	+5.7
Special Promotion Funds	11.0	+4.8
Space	144.7	+9.9
Nuclear Energy	315.2	+2.9
SOR (Spring-8)	7.0	+43.0
Ocean Research	11.4	+6.8
ERATO	6.3	+12.1
Sakigake	1.0	+117.0
Human Genome	1.1	+20.9

Source: **Nature**, 1992.

of life and economic growth. The AMPP will pay particular attention to the interfaces between universities, government laboratories and industry, and on the process of technology transfer from basic research to commercial application. The budgets for AMPP are given in Table 2.

In the case of Japan, it is widely recognised that the country faces considerable difficulties in the conduct of basic scientific research[17], but it would be a serious mistake to under estimate the massive effort and resources that have been directed in recent years towards a resolution of the needs for creative scientific research. Scores of modern R&D laboratories have been constructed by many Japanese corporations, while internationalisation and location of R&D facilities abroad enable such companies to tap the world scientific knowledge base and recruit the best of local scientific researchers. The determination to conquer high technology activities is underscored by the fact[18] that by the year 2000 Japan will apportion 3.5 per cent of its gross domestic product (GDP) to R&D activities as compared to 3 per cent in the USA, and will employ nearly twice (350,000) the number of a scientists and engineers in high-tech innovative projects as the USA.

A recent significant and unprecedented move has been the formation of a powerful pressure group within Japan's former ruling Liberal Democratic Party, headed by the former head of the Science and Technology Agency, Kishiro Nakamura. The 'special committee to reinforce maintenance of the basic research base and international research cooperation activity' is calling for dramatic increases in government spending on research. Committee members include politicians with strong links to science-related ministries and, importantly, the Ministry of Finance. Both leading academics and industrialists[19] are voicing strong concern over the rundown of Japanese universities and the shortage of human and financial resources, which would undermine Japan's shift to high technology. In recognition of the rising political and industrial significance of basic research nationally and internationally, the Japanese Ministry of Finance decided in January 1992 to invest US$ 800 million (compared to a request of US$ 600 million from Monbusho, the education Ministry) in renovating Japan's major universities and strengthening the basic research funding system. This also opened the door for Japan to offer financial support to the Superconducting Super Collider (SSC) in the United States, for which they had been under repeated and intense pressure by President Bush. However, the SSC was cancelled in late 1993, with both positive and negative implications for Japan. The budgets for science and technology approved by the Cabinet on 28 December 1991, are shown[20] below in Table 3. The 10 per cent increase for STA's space budget is mainly intended for Japan's contribution to the USA space station and Japan's new H-11 rocket, to be launched in 1993. It should be noted that much emphasis is placed in Japan on the development of aerospace as a next generation high technology for the 21st century, with large intersectoral ramifications in the economy.

3.2 New technologies provide a strategic weapon in global competition

A broadly based, of necessity, scientific research effort and the display of inventive

TABLE 4: US NATIONAL CRITICAL TECHNOLOGIES

MATERIALS

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

MANUFACTURING

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

INFORMATION AND COMMUNICATIONS

- Software
- Microelectronics and optoelectronics
- High-performance computing and networking
- High-definition imaging and displays
- Senors and signal processing
- Data storage and peripherals
- Computer simulation and modelling

BIOTECHNOLOGIES AND LIFE SCIENCES

- Applied molecular biology
- Medical technology

AERONAUTICS AND SURFACE TRANSPORTATION

- Aeronautics
- Surface transportation technologies

ENERGY AND ENVIRONMENT

- Energy technologies
- Pollution minimisation, remediation and waste management

creativity are all but irrelevant unless they ultimately lead to the development of useful technologies. Irrespective of where new technological inventions originate, the most successful firms and industries are those that can incorporate them fast and efficiently into new innovative and commercially viable products and processes, exhibiting faster time to the market place, than competitors. In a fiercely competitive global market, simultaneous or concurrent engineering tools, enable firms to engage in an integrated and simultaneous R&D, product design and manufacturing approach, which, as a consequence, results in faster product renewal and continuous innovation. Faster product innovation moreover, enables firms to incorporate the latest inventions and technological innovations into new more sophisticated consumer durables or industrial machinery and equipment reaching the market place in record time. Commercial and industrial success thus resides in those institutional mechanisms and design and manufacturing engineering capabilities that enable firms to transmit technological advances into commercial applications. Technology is unquestionably a critical weapon for acquired competitive advantage in the world market. The possession of engineering, processing and manufacturing skills, on the other hand, provides the essential prerequisite for the successful transmission of science-based technological breakthroughs into commercial application and competitive advantage. This is best understood in Japan, and is being relentlessly demonstrated in industry after industry, from car production to semiconductors and now new materials.

A recent report[21] by a panel appointed by the United States National Academy of Science and Engineering and the Institute of Medicine pointed to a significantly larger time lag between product design and commercialisation in USA industry as compared to foreign competitors. It called for a Civilian Technology Corporation (CTC) financed by a one-time outlay (US$ 5 billion), which would create joint R&D ventures with the private sector. Such projects would be initiated by industry. The report, in a clear response to Japanese experience and with no reference to an 'industrial policy', highlighted the need for 'a new alliance between government and industry in pre-commercial areas', calling for strong government financial support of high technology development and programmes which would facilitate the speedier commercialisation of new discoveries.

In an important recent study[22], submitted to President Bush in March 1991, the US National Critical Technologies Panel has selected 22 technologies deemed critical for military and economic competitiveness, which therefore require concentrated effort. The panel placed special emphasis on the need for US industry to adopt an integrated and hence continuous improvement approach to both product development and associated manufacturing processes to produce them. Given the strong US scientific knowledge base, the parallel concern is for the more effective translation of resulting technological advances into high-quality, high-performance, low-cost commercial products and military systems. The technologies selected are listed in Table 4.

In keeping with the central objective of effectively exploiting new technology, five of the selected technologies refer to processing and manufacturing technologies:

1. Materials synthesis and processing;
2. Micro- and nanofabrication;
3. Intelligent processing equipment;
4. Flexible computer integrated manufacturing;
5. Systems management technologies.

Moreover, stress is also laid on manufacturing and product development issues associated with the other 17 critical technologies. The panel also recognised that some technologies have a generic impact in that they constitute the basic 'building blocks' of nearly every sector in the economy. These fall under Materials, Manufacturing and Information and Communications. At the same time several technologies are enabling or supportive of other critical technologies. Thus, materials, micro-electronics, simulation and modelling, and manufacturing are singled out as essential for improvements in virtually all other critical technologies.

4. INDUSTRIAL AND TECHNOLOGY POLICY IN THE 1990s

4.1 Materials synthesis and processing links basic science to manufacturing engineering

As the analysis of thisstudy makes clear the materials revolution entails the arrival of a truly generic science-based technology with an impact on all sectors of the economy. At the same time the design and reliable processing of high performance functional and structural materials engineered to meet exacting requirements in specific applications is itself supportive of many critical technologies that are themselves both enabling, and in some cases, generic in their impact, as for example micro- and opto-electronics. But more than this, new materials offer a dramatic solution to the problem of incorporating advances in basic science and resulting technological breakthroughs into commercial applications and fast product renewal across industry. Materials science and engineering integrates many of the physical sciences with processing and manufacturing engineering. Materials synthesis and processing is rooted not only in the basic sciences, but also possesses a strong industrial and engineering component. The possession of materials synthesis and processing capabilities facilitates cost effective, reproducible fabrication of both novel and conventional materials possessing vastly superior properties and tailored to user needs. New materials, moreover, necessitate the integration of material or component, product and manufacturing design engineering in a simultaneous integrated approach, be it in aerospace, or, sporting goods[25], or automobile application. Materials synthesis and processing has therefore acquired a pre-eminent position in the generation of new technologies and their commercialisation, linking the basic sciences to the engineering and manufacturing base of the economy. Moreover, and this constitutes another major proposition of this book, materials synthesis and processing[26] in the context of simultaneous manufacture, transmits basic scientific inventions fast and efficiently into high technology application and fast product renewal underpinning competitive advantage in world class manufacture. However, this presupposes that an economy possesses considerable engineering skills and a strong manufacturing base. Of course, as science linkages to industry and commercial application increase, the boundaries between basic and applied research will become increasingly blurred.

Summary of the argument so far

> Technology today underpins most innovations required for sustainable industrial competitiveness, trade and growth. Hence "industrial policy" is "inextricably" linked to "technology policy", and thereby to "science policy". However developments in recent years strongly highlight the fact that "industrial" or "technology" policy has become indissolubly linked to materials policy across both industrialised and industrialising economies. The analysis and evidence in the present study indicate that materials synthesis and processing forges a crucial link between the basic sciences, the engineering and manufacturing base of the economy, and the speedy commercialisation of new technologies in the context of simultaneous manufacture. We have already pointed to the fact that all major technologies today are dependent on solutions offered by materials science and engineering. The availability of high-performance functional and structural materials conditions further advances in a range of critical technologies with economy-wide technological spillover effects, while conferring global competitive superiority onto national branches of high technology and other manufacturing industries. It is therefore a dangerous anachronism to neglect the crucial role of advanced materials in any attempt to formulate an 'industrial' or 'technology' policy in the 1990s.

4.2 Is there a need for an industrial or technology policy?

Lewis M. Branscomb in a recent contribution[27] points out that the real issue here concerns the kind of government technology policies and programmes that make sense in the present competitive environment, rather than whether the USA should have a technology policy. Supply side policies aimed at creating new technologies informed much of the accepted United States technology policy in the post-war years. This comprised of considerable government funding of basic research at universities with fundamental breakthroughs eventually feeding through into new technologies, products and industries, and secondly, investment in technology development by federal agencies, dominated by defence and space related R&D. This approach has been rendered obsolete, he claims, by developments over the last decade, which place a premium not on fundamental breakthroughs in basic research but rather on low-cost manufacturing of high quality products. In short, competitive success depends on the ability of companies to absorb new technologies, irrespective of place of origin, and apply them quickly. He rightly, points to the example of Japanese consumer electronics, where success was predicated upon the successful commercialisation of technologies developed elsewhere (e.g. the USA invented video cassette recorders) and on cumulative learning by doing in manufacturing processes. Government's responsibility therefore lies less in the stimulation of technological innovation, but rather on a "demand" orientated technology policy, aimed at speeding up commercialisation by encouraging collaborative research between firms and between government, university and industry labboratories, investing in the necessary technology infrastructure and assisting business to develop techniques that would increase the productiveness of business. A number of issues must be addressed here.

While western policy-makers and industry agonize over the necessity and form of industrial or technology policy, Japan is well on is way towards a strategic orientation of its industry into the next century and domination of a "list of critical technologies"[28] through the exploitation of her superior processing, engineering and manufacturing skills. It is not as Branscomb argues a matter of emphasising application rather than creation of new technologies, for the simple reason that most high technology today is science-based or science driven. Basic science must be supported because it provides the knowledge source for high technology, and this has been recognised by Japan as it moves to conquer such fields. Despite her considerable shortcomings in basic science noted earlier on, a massive effort is under way to improve the domestic basic research infrastructure, at university, industry and government laboratories, internationalise and tap into the world scientific knowledge base[29] in both the physical and life sciences. For while complete dependence on foreign scientific input and state-of-the-art components and technologies is tantamount to competitive suicide, self-sufficiency is neither possible, nor desirable, since access to fast changing basic and applied global frontier scientific progress is of the essence today, and the Japanese government and industry are keenly aware of this. It would be absurd for western governments to now neglect basic and applied science. Nonetheless, the recent emphasis on engineering and manufacturing skills and technologies, and government-industry-university R&D collaboration is a necessary redress to decades of neglect in these fields.

4.3 Market failure and industrial policy

Arguments[30] for the desirability of *laissez faire* usually rest on a set of restrictive assumptions. Where these assumptions are violated in practice, markets are said to "fail". Market failure and the consequent misallocation of resources provides a theoretical justification for corrective government intervention. Arguments for the desirability of industrial policy are usually cast in the form of market failure considerations. The differing conceptual basis for government intervention in Japan and the USA is given in Table 5.

Industrial policy is, in many cases loosely defined, but in the main[31] it is taken to mean the use of a government's authority, resources and custom built policy instruments in order to

TABLE 5: CONCEPTUAL FRAMEWORK FOR GOVERNMENT INTERVENTION

Japan and the USA

JAPAN	USA
Market Imperfections	**Market Failures**
Capital market deficiencies	Externalities
Excessive competition	Neglect of collective good
Regional maldistribution of resources	Antitrust abuse
Industrial disorderliness	Business cycles
Production inefficiencies	Manpower needs
Resource misallocation (non-priority sectors)	Excessive risks
Problems related to industrial structure	Unemployment
	Redistribution
	Social injustices (need for affirmative action, etc.)
	Loss of international competitiveness
Economic Security	**National Security**
Structural maladjustments	Supply disruptions (raw materials)
	Foreign market closure
	Dangerous foreign dependence
	Loss of competitiveness in vital industries
	Need for technological edge
Industrial Policy – fallout effects	**Distortions from government intervention**
Assistance for small- and medium-sized enterprises	Contagion effects of policies (taxes, subsidies)
	Remedial policies
Industrial catch-up	
Infant industry vulnerabilities	
Threat of lower value added; unacceptability of certain areas of comparative advantage	
Loss of industrial autonomy	

Source: Daniel I. Okimoto, *Between MITI and the Market*, 1989, p.53.

encourage resources to flow into specific industries, or firms, according to certain criteria, priorities, needs, and circumstances faced by the industries in question. The underlying premise for such government action is that sole reliance on the invisible hand and/or broadly based macroeconomic policy would fail to produce the desired sectoral outcome. Care must be exercised here. Ever since the Industrial Revolution our economies have been characterised by uneven growth of branches of industry. Some industries grow fast while others reach maturity in their life cycle, stagnate and subsequently decline[32] in relative importance, as a result of the natural operation of market forces. If then comparative advantage in an economy is shifting away from traditional commodity production in 'smokestack' basic industries to new high technology areas such as computers, telecommunications and biotechnologies, market incentives would presumably encourage factors of production to shift to the high-tech activities and out of shrinking industries. What is the function of industrial policy then? Here the government would need to demonstrate that resources, if left to pure market forces, are shifting "too slowly" into the high technology sectors or "too slowly" out of the declining sectors[33]. That is, some form of market failure persists which requires corrective interventionist action on the part of the government.

In the USA popular arguments for industrial policy have concentrated on a set of four criteria for identifying industries, the growth of which ought to be overtly encouraged by the government. Firstly, shifting the mix of industries towards those with high value added per worker could raise national income. Secondly, governments must encourage the expansion of industries producing intermediate goods, like steel, which are used by a variety of industries in the rest of the economy. Thirdly, given the interplay of uneven patterns of technical change, shifting demand patterns and changing comparative advantage, sectors will display differential rates of growth. If the government can predict which industries will grow fastest, then it should encourage factors to flow into them, i.e. "pick winning industries" with the highest growth potential. Fourthly, industrial policy can be designed as a defensive measure to protect US industry from competitive pressures posed by the support provided by a foreign government to that industry. If the USA does not respond to the targeting of a specific industry by a foreign government then key industries in the USA may disappear. A number of economists[34] do not find these arguments convincing from the point of view of market failure considerations and hence dismiss the need for industrial policy if justification is sought solely on the grounds advanced above.

They argue that industrial policy must demonstrate a preexisting domestic market failure that the policy is designed to correct or offset. Two major market failures have been identified in advanced industrialised market economies which are relevant for industrial policy. The first refers to high-technology industries and the presence of externalities in the generation and appropriation of new knowledge. The second refers to the existence of monopoly profits in imperfectly competitive concentrated industries. This latter market failure provides justification for industrial targeting and strategic trade policy.

Where firms invest in the generation of new knowledge but can only appropriate a part of the benefit, then this gives rise to externalities in the form of 'free' benefits to other firms and hence leads to extra output or marginal social benefit to the economy. If it can be demonstrated that these externalities in knowledge are large then there is a strong case for subsidising the industries in question. This requirement can be satisfied by a group of industries termed high technology industries, defined on the basis of above average employment of scientists and engineers and/or R&D expenditures, such as electronics, aerospace, agrochemicals, pharmaceutica, and telecommunications. It can be argued that firms in high technology industries are primarily engaged in the creation of knowledge via large R&D expenditures and the underwriting of new technologies and products over a long time horizon before returns accrue. Under weak intellectual property right protection laws, the free market would provide small incentives for innovation by firms in high technology, resulting in a socially suboptimal rate of innovation. There is therefore a strong *prima facie* case for government subsidy targeted at those industries and activities where market failure demonstrably occurs, that is at the point[35] of generation of knowledge, which cannot be appropriated by the investing firm, and which results in large technological spillovers to the economy. The optimal subsidy would depend on the empirical size of the perceived technological spillover effects, and hence the difference between social returns and private returns to R&D expenditures, which would persist even in the presence of (effective) patent protection.

4.4 High technology industries

High technology industries are of increasing importance to national economies in both developed and the newly industrialising economies, in terms of technical change, skills and high wage job creation, competitiveness and trade. As Tyson[36] observes, such industries are in possession of several characteristics, such as imperfectly competitive market structures, the display of strategic behaviour, the existence of dynamic scale, scope and learning economies and technological spillovers, which provide policy-makers with ample justification for the implementation of interventionist measures to support and protect them. It is not surprising that the targeting, promotion and protection of domestic high technology industries by many governments around the world is giving rise to trade conflicts and increasingly so.

Tyson argues that high-technology industries are very important for the performance of the US economy and national economic welfare for the following reasons. Firstly, they account for nearly 60 per cent of manufacturing R&D, while comprising of 20 per cent of manufacturing output and 24 per cent of manufacturing value added. Within this, the electronics complex (computers and office equipment, communications, electronic components, and audio and video equipment)and the aerospace group of industries (aircraft and missiles) account for nearly two thirds of total high technology R&D. Private R&D in these industries provides spillover benefits to other firms and consumers not only in the US, but also abroad. Therefore social rates of return to R&D expenditures exceed, quite substantially, private returns. These R&D externalities provide the "most compelling reason for the long run importance of these industries to the US economy". Secondly, high technology sectors account for a higher proportion of scientists and engineers per 1,000 employees than the average for all manufacturing. Higher skill intensity is associated with high productivity and consequently a higher level of compensation than the rest of manufacturing industries, which display higher productivity and wages than most service industries. High technology activities provide large and persistent quasi-rents or higher returns to labour than in many other industries. Therefore high technology is 'strategic' in Paul Krugman's sense[37], providing both large R&D spillover effects and excess returns[38].

4.5 High technology R&D spillovers – local and global

High-technology industries are of a peculiar, indeed strategic, importance to national economies. Their influence extends beyond the observed impact on the generation of high skill, high wage jobs, above average R&D expenditures, high rates of productivity growth and export performance. Rather, their influence is far more significant, residing in the pervasive externalities associated with their research and technology development activities. Interesting issues arise here. Where the R&D spillovers so generated flow not only outside a firm but also a national economy thereby contributing to the global stock of knowledge, R&D effort and technological innovation, then the promotion of high technology industries and the conditions for it to flourish enhances global welfare. If effective R&D and technological innovation in core high technologies entail the synergistic combination of complementary inputs in domestic and, increasingly, cross-border alliances and joint ventures between firms, then the creation of a national and uniform multilateral framework facilitating such cooperative moves ought to be the primary aim[39] of policy making in this area. At the same time the formation of inter-firm alliances provides a mechanism for the transfer of technology[40] and skills across firms and national economies, leading in conditions of an asymmetry of aims and technological strengths, to the erosion of the in-house and domestic technological strengths of one of the participants. Clearly, if all knowledge generated by high-technology firms within national boundaries can easily flow outside through a variety of appropriating mechanisms including cross-border alliances, thereby contributing to the R&D effort, technology development and competitiveness of other nations, then this weakens the case for country-specific measure to create a purely domestic high technology base to the exclusion of foreign firms. Nevertheless, strategic promotion of high technology by one nation would confer cumulative gains in national welfare, whereas the loss of competitiveness of national high technology branches would result in unacceptable cumulative and widespread losses in national well-being. Herein lies the incentive and rationale for government intervention to promote, or arrest the decline of national high technology branches and the roots of trade conflict consequent upon such action. We take up some of these arguments below.

In the presence of excess returns generated by high technology discussed above, attempts by countries to support these industries in order to capture a larger share of global rents constitute a zero sum game where one country's gain is another country's loss. Such gains and losses in high skill, high wage industries across national boundaries can be substantial and are in essence local or national. On the other hand, knowledge, its generation, appropriation and diffusion raises a wider set of issues. Tyson (1992, pp. 39-42), building upon Krugman (1987) points out that R&D spillover effects cannot always be contained within a local or national framework, but are becoming increasingly global in their effect. Mechanisms through which knowledge generated by a firm within national boundaries can be transmitted externally include joint ventures, R&D alliances, licensing, professional journals and societies as well as dubious practices such as patent infringement, 'reverse engineering', industrial espionage, headhunting of key personnel and so on. Through such mechanisms knowledge creation by a firm in one country provides global benefits. However, the imposition of tighter intellectual property right laws on competing economies can reduce the global spillover benefits arising from privately funded R&D in the domestic economy. And delays in the international transmission of knowledge can still confer first mover advantages in terms of the ability of the innovating firm to appropriate much of the private returns accruing before entry by foreign firms. In addition to issues appertaining to knowledge that by its nature can be transmitted relatively easily across frontiers, a second type of knowledge can be identified. The latter relates to firm-specific knowledge such as that which arises from R&D on in-house production processes. This type of knowledge can be fully and privately appropriated by the firm for long periods of time, even in the absence of institutional or other obstacles to its international transmission.

A third type of knowledge exists which generates benefits, which although not fully appropriated by the firm nevertheless remain confined 'locally' within a national setting. This idea is related to the observed tendency of firms in an industry to cluster close to each other within localities of a national economy. Examples[41] include the electronics industry cluster in Silicon Valley and the "ceramics corridor" in the USA, the clothing industry in parts of Italy, etc. Firms tend to form agglomerations within national settings due to the existence of externalities of a local or more broadly, national nature. These could take the form[42] of a common and relevant academic, scientific and technical infrastructure upon which firms draw and through which they can interact and learn from each other, the availability of a skilled labour force, the emergence of a network of specialised suppliers and supporting technical services, and the formation over time of information networks, professional contacts and linkages. These 'local' or national external economies can be said to be cumulative and self-reinforcing. A country or a region with a competitive, innovative and growing set of industries will tend to generate additional networks of supporting infrastructure, information, skills and specialised inputs. These in turn will tend to further strengthen the competitiveness of the industries with which they enjoy complex, two way linkages. Conversely, the loss of international competitiveness and decline of the industries in question can lead to a contraction and irreparable damage inflicted upon the networks of supporting knowledge base, skills, and specialised inputs. This could further erode the competitive position of this and related industries in a process of cumulative contraction. Therefore, the existence of 'local' externalities of a regional or national nature has powerful implications for the role of high-technology in conferring strategic benefits to a domestic economy.

High technology industries are by definition the most research intensive and innovative set of industries within an economy. However, the process by which they generate and diffuse new knowledge and technologies depends in part on the ability to draw upon locally accumulated stocks of interrelated and mutually supporting stocks of knowledge, skills, experience and technical know-how. That is, innovation in high technology requires and builds upon a broad array of a complementary network of professional contacts, research centres, metrology and standards institutes, academic circles, supporting scientific and technical infrastructure and services, and specialized inputs.

Successful R&D and technical change in high technology further reinforces, expands and deepens the local accumulation of knowledge and specialised inputs, thereby providing the impetus for further innovation in this and other sectors of the economy. The argument is strengthened further from the evidence pointing to the fact that much of the stock of knowledge, experience and know-how accumulated by firms and supplier networks in a particular locality derives from strong learning by the formal and informal interaction of scientists and engineers across the academic and private research infrastructure in the process of conducting R&D. There are therefore strong "learning by doing" and "learning by conducting R&D" effects underlying the local or national accumulation of knowledge and skills, proceeding across a wide and interdependent front. This type of knowledge cannot suddenly be learned through the purchase of products and components embodying it in the open market. On the other hand the local accumulation of such self reinforcing benefits is crucial in the ability of an industry's or an economy's research base to appropriate and utilise knowledge generated elsewhere in the world. Such observations acquire a pivotal, strategic significance in the scientific and technological conditions prevailing in the 1990s.

The local and self reinforcing nature of high technology R&D externalities constitutes a major component of a nation's technological capabilities. As Tyson points out, the loss of high technology sectors entails a serious loss of domestic technology competencies. Given the importance of these ideas we examine them in more detail below and then proceed to integrate them with the findings of this study. The implications are far reaching indeed.

4.6 High technology and strategic trade and industrial policy

In examining the evolution of the semiconductor industry Borrus, Tyson and Zysman[43] raise a number of crucial issues of relevance to our present discussion. Firstly, their investigations provide empirical support for the proposition that strategic government policy, even if temporary, can confer enduring effects and global competitive advantages to national firms operating in high technology, research intensive industries within imperfectly competitive market structures. This is consistent with the views of the new trade theory school which rejects the policy conclusions flowing from the highly unrealistic and restrictive assumptions upon which the traditional neoclassical comparative advantage trade model rests. The new trade theorists[44] focus attention on the determinants, resulting patterns and welfare distribution consequences of international trade under conditions which diverge from the assumption of perfect competition, constant returns to scale, and the absence of externalities, amongst others. It can be demonstrated, at least theoretically, that in the more realistic case, strategic government policy can have a permanent and radical impact on trade patterns and, importantly, can result in a national welfare outcome which is better than the free trade outcome. Countries can theoretically acquire permanent advantage in industry after industry through government support of industries at an early stage of travelling down their steep learning curves. In this connection, Tyson[45] argues that technology intensive industries possess characteristics which violate the assumptions of trade theory and the essentially static concepts informing US trade policy. Such industries display decreasing costs and quality improvements with increasing scale. The creation of new knowledge and advancing technologies generate positive spillovers or externalities to the rest of the economy. And the existence of barriers to entry create strategic behaviour on the part of firms. Consequently, national competitive advantage does not derive from natural factor endowments as maintained by the Hecksher-Ohlin theory of international trade, which dominates much of policy formation in this area. Rather, competitive advantage where high technology is concerned is dynamically acquired and depends on the strategic interaction between firms and governments and between firms and governments abroad. The new trade theory taking root in the last 10-15 years therefore argues that in the presence of increasing returns, technological externalities and imperfect competition in monopolistic or oligopolistic industries, the pursuit of free trade may not be the best policy option. The domestic promotion or protection of high technology industries can harm foreign welfare, and *vice versa*. Moreover, support for R&D in such knowledge-intensive industries as semiconductors, could conceivably lead to the generation of domestic and global R&D spillovers. This takes us to a crucial set of related ideas.

Secondly then, Borrus et al. (1986), argue that the semiconductor case contains richer implications than those deriving from the side of strategic trade theory and policy alone. Whether the government targets one or more, high technology industries capable of generating large technological externalities accruing to an array of several other sectors in the economy, then the national welfare effects can be far more pronounced, widespread and dramatic than the new trade theory would suggest. That is, the strategic targeting of sectors with large spillover effects will not only create enduring competitive and trade advantages for the sectors concerned, but will, in addition, strengthen the competitive position of an extended set of directly and indirectly related sectors thus resulting in substantial improvements in national well being. Several interrelated issues arise, which are taken up in the following sections, closely integrated with the findings and ideas explored in this study.

The available evidence suggests that for a specific technological breakthrough or advance to occur, it is normally the case that prior advances have taken place in the technology in question as well as in a set of complementary and interrelated technologies and associated infrastructure into which the innovating entity is embedded. The existence of technological interdependence and complementarity requiring that certain cumulative preconditions have to be met on a wide front if the innovation process is to be successful, is, indeed, a powerful idea, and has, moreover, important implications for industrial policy, especially where high-technology is concerned. The ability of US semiconductor firms to conduct successful frontier R&D depended crucially on the availability of a domestic network of supporting infrastructure and accumulated past and contemporary technologies on which the firms could easily draw in their research and technology development effort. Here, a highly developed and extensive domestic scientific and technological infrastructure consisting of formal and informal networks of academic centres of excellence, government laboratories, materials research centres, standards and metrology institutes, private industrial laboratories, suppliers of specialised chemicals, electronic ceramics and metallic materials, and, importantly, semiconductor equipment suppliers, as well as a proliferation of downstream user industries in electronic consumer durables, computers, telecommunications and aerospace/defense, played a decisive role. On the one hand successful R&D in semiconductor technologies both promotes the well being and expansion of the associated scientific, supplier and supportive infrastructure, and provides necessary inputs and critical technologies enhancing the R&D effect and competitiveness of a chain of downstream electronics and information related industries. Consequently, were the competitive position of the domestic semiconductor industry to deteriorate, then this could cause a cumulative, irreversible and devastating destruction of (a) the scientific communities and associated supplier infrastructure upon which technical change and competitive fabrication of semiconductors depends, (b) the ability to innovate in critical semiconductor technologies as they move towards VLSI, ULSI and quantum devices and nanoprocessing technologies, and (c) the ability to engage in product and process innovation in a wide range of micro-electronics related industries with large intersectoral linkages and effects in the economy. On the other hand, relying on information flows across international frontiers may not be as efficient as in networks established within the domestic scientific community. Moreover, access to critical technologies and components from abroad may not be timely or even forthcoming, may be of inferior quality and may not be susceptible to any understanding of the process whereby the technology was developed, how it can be modified and how it relates to your own product and technology development effort. Relying on your competitors for the provision of critical technologies embodied in components, devices and systems may not be rational business or rational competitive strategy. But there are further problems. Looking at semiconductors again, successful innovation and growth in this industry leads to a cumulative build-up of learning, skills and experience in a broad range of scientific and engineering disciplines, the supplier base and processing, fabrication equipment, and instrumentation/measurement technologies facilitating the transition towards the next generation optoelectronic, photonic, mechatronic and optomechanic technologies and their widespread application. There are severe penalties for late entry and in many cases it may be impossible due to 'closed doors' on specific core technologies and the steep learning curves of 'learning by R&D and doing' across successive trajectories of interrelated technologies over time. Technology catch-up from a position of minimal or declining domestic research competencies in the scientific and technological conditions of the 1990s may prove far more difficult than in the 1960s and 1970s. Viewing the problem from a somewhat different angle, an economy which allows key competencies and components to pass on to competitors on whom it then relies for their provision, seriously risks its progressive 'deskilling', erosion of its research and supplier base, deterioration of ability to conduct frontier R&D and progressive loss of competitive ..ss in a cascading series of current and new generation technologies and industries. These considerations needless to say do not figure prominently in mainstream static, or at best comparative static, trade theory models, under the assumptions that all countries have access to the same unchanging technology, extolling the virtues of specialisation, participation in the international division of labour and engaging in mutually beneficial free market exchange. Relying on cheaper Japanese semiconductor imports entails static welfare gains to US 'consumers' but this may be outweighed by the progressive domestic deskilling, loss of innovative potential and consequent long run decline in national welfare. Yet it is these long run dynamic spillover effects that ought to exercise theory and policy making. It is, at least implicitly, these kind of considerations that have led to the formulation of ambitious industrial strategies in the Far East, which build upon accumulated skills and research infrastructure in order to restructure towards next generation technologies and industries. Central to these is the acquisition of domestic competencies in a range of critical input technologies, namely advanced materials, deemed essential for a range of downstream manufacturing and high-technology activities. Neither are market forces on their own viewed as able to shift resources at an acceptable rate, if at all, into these critical input technologies, nor is it viewed acceptable or feasible to rely entirely on the world market for their availability. We take up these ideas below.

Certain input-producing technologies then can have a pervasive impact on the domestic science and research base and associated infrastructure, in a complex, self reinforcing virtuous circle of cumulative expansion or vicious circle of cumulative contraction, with serious repercussions for innovation, competitiveness and growth in a series of interrelated industries. In these circumstances, the loss of competitiveness and consequent decline of such pivotal generic and enabling technologies can have disasterous implications for national well being, as a result of the erosion of the science and research base and the slowing-down of the process of innovation and diffusion of new technologies in many industries. The existence of potentially large positive or negative dynamic inter- and intra-industry technological and R&D spillovers provides a strong case for government support of high-technology sectors, beyond the strategic trade theory considerations.

It could be, and sometimes is, argued that the domestic erosion of a substantial portion of an industry such as semiconductors and its associated research, supplier and equipment market base is not so serious, since the relevant knowledge, components and technologies can be easily and speedily acquired by plugging into the international scientific community and participating in world trade[46]. Whatever the merits of such a view for earlier technologies, it is doubtful whether today, and increasingly so in the future, purchasers of complex,

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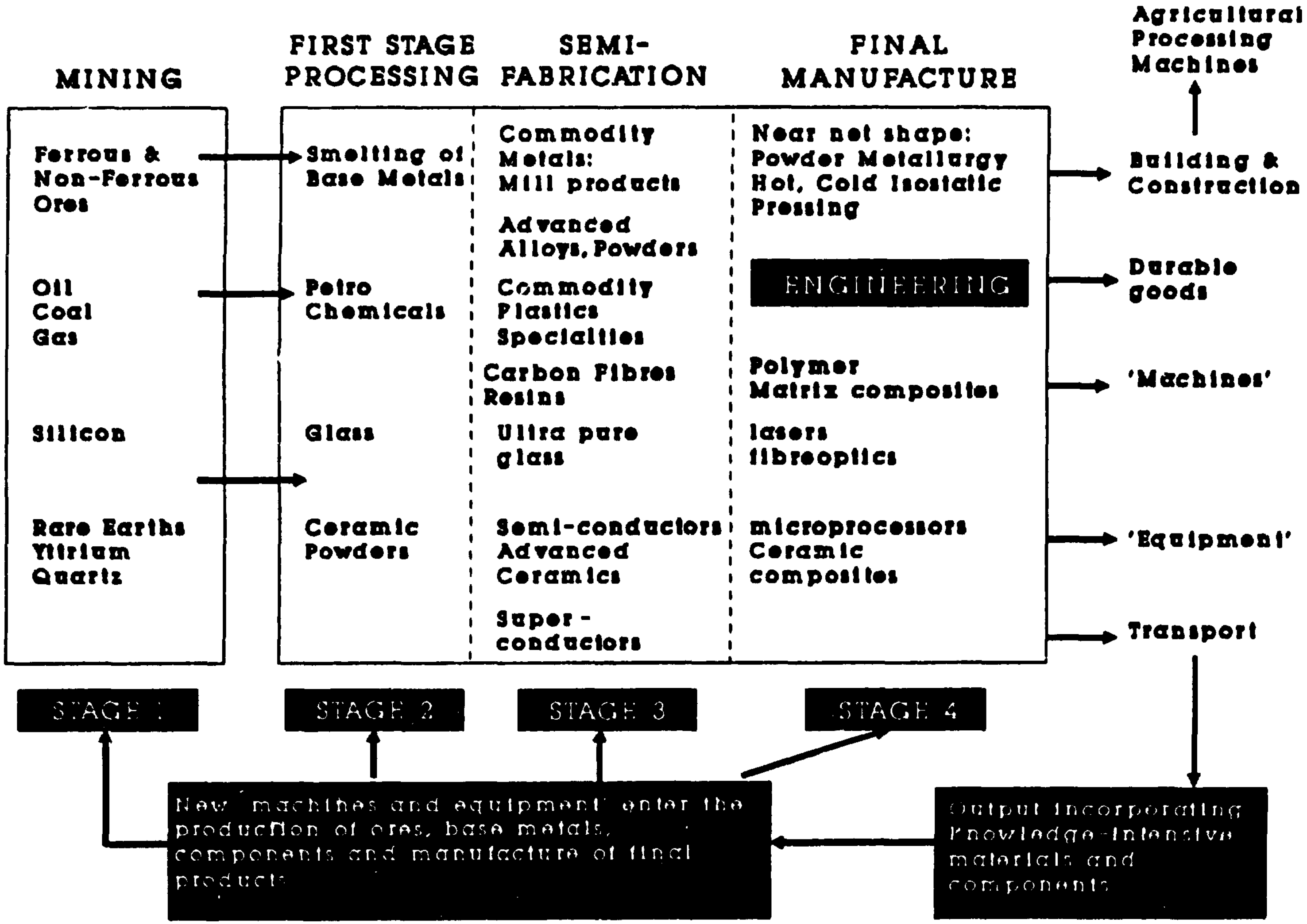


knowledge-intensive components and systems in the open market would be able to "unbundle" the cumulative skills and technologies residing in them, or fully comprehend, absorb and adapt them to their own innovation needs. This problem is reinforced by the convergence of several technologies and the synergy of diverse competence and cumulative skills required to master and successfully develop new technologies and products in a specific field be it HDTV, aircraft engines, aluminium-intensive vehicles or Maglev trains. Attempting to simply plug externally acquired key components into existing or developing technologies may be difficult or impossible or place the firm at a distinct competitive disadvantage. Moreover, it entails the real danger of a progressive loss of in-house or national skills and know-how in core technologies and a hollowing out not only in terms of manufacturing capacity but also in innovative capacity in specific industries. Our comments here merely point to some emerging dangers and tendencies that must be confronted on a case by case approach by corporate and national strategies in the 1990s. They should not be construed as arguing that all countries should be competent in all high technology industries and/or all components, materials and devices. Below, we examine the role of advanced materials in the context of technical interdependencies in the structure of production.

4.7 Advanced materials, the structure of production, technological interdependence and R&D spillover effects

Discussions of what constitutes a strategic industry normally take place at the level of market structure, the existence of "excess" returns to factors of production and divergences between private and social returns to R&D investment. This is consistent with much of modern, mainstream economics preoccupied as it is with analysing the economic system at the level of markets and prices, with little attention to the underlying characteristics of concrete production processes and intersectoral technological interdependencies in industrial economies. However, the key to understanding "strategic" industries or industries of a prior, critical significance to the functioning of an economic system lies in the identification of the sequential and circular technological interdependencies underlying market interactions and the location of a specific technology and industry in the structure of production[47].

4.7.1 Technological interdependence, clusters of innovation and strategic industries

For over two centuries following the Industrial Revolution, the raw and processed basic materials producing sectors have provided the life blood of industrial production and growth. New products and processing technologies were designed around existing traditional materials[48] in possession of empirically, and increasingly scientifically understood properties and limitations. Cost and price exercised a decisive influence on the long-run dynamics of inter-material substitution, while specific materials laid claim to reasonably well defined user markets and applications. Key material inputs have also been associated with and, in the main, have been responsible for the competitiveness and growth of major industries and economies (e.g. coal and iron, steel, oil, silicon) over successive historical epochs[49].

The constraints imposed by pre-existing materials have now been lifted with the arrival of the materials revolution spreading through the earlier stages of production and the traditional materials producing industries. There are many consequences from this, but we will only focus on a small subset of these here. The constellation of properties and performance characteristics required by user industries is now a driver for materials research and development in order to tailor materials to customer specifications. At the same time, the new materials scientific and engineering base provides enormous scope for autonomous improvements of existing materials (through intelligent processing for example), and the creation of entirely new materials for existing or entirely new or unforeseen application. All in all, the new developments necessitate the forging of close vertical relationships between materials producers and users in industry.

Clearly materials have always had a crucial role to play in industrial development, although this has gone largely unnoticed in the literature. Today, however, industries located at the earlier stages in the structure of production have acquired a pivotal, indeed determining, role in the functioning, innovative potential and growth of industrialised and industrialising economies. In so far as our present discussion is concerned, not only are new materials emerging as an R&D-intensive high technology set of activities, but technical change in an array of high technology industries is constrained and conditioned by the creation and application of the requisite materials systems.

The flow of advanced materials systems, components, devices and sub-assemblies, can exercise considerable direct and indirect influence on the generation and diffusion of new technologies in an expanding array of downstream industries and thereby on investment and economic activity as a whole. New materials require the redesign of products and manufacturing processes, thus leading to the obsolescence of existing stock of fixed capital and associated infrastructure, and provide the incentive and opportunity for the progressive diffusion of more efficient and competitive technologies in the productive base of the economy. At the same time, new knowledge-intensive machinery, equipment and processing plant, which embody the fusion of advanced materials, electronic and sensor technologies, travel back and progressively transform, indeed revolutionise, the mining, materials processing and fabrication and the machine-producing engineering sectors. The materials industries can then generate a process of cumulative and mutually reinforcing, and to a degree, interdependent technological advance and fixed capital formation across a wide front. They constitute the strategic industries par excellence in the 1990s not only by virtue of the knowledge-, skill-, science-, and R&D-intensity, but also due to their location in the physico-technical interdependencies and vertical, horizontal and circular flows characterising modem industrial systems producing and using fixed capital.

Economic and technological forces are today inexorably leading to a restructuring of industry throughout the IAC's and several NIE's towards high technology activities which strongly depend on access to and mastery of frontier scientific and engineering knowledge and associated basic research. Furthermore, we are witnessing the steady erosion of the boundaries between the physical sciences and even between them and the life sciences, while several complex technologies are currently converging. A precondition for successful R&D and innovation in high technology is therefore the existence of a domestic, highly developed scientific and engineering infrastructure and network of multidisciplinary centres of excellence on which firms can draw and synergistically combine in their research and development. Collaborative alliances between firms, and between firms, universities and government laboratories play a crucial role, but are not a substitute for in-house R&D capabilities. Similarly, access to foreign sources of frontier scientific and technological advance, although important is not a substitute for domestic frontier scientific skills and competence. Once the latter are run down then foreign advances in knowledge may not be comprehensible let alone appropriable, given the speed and complexity of additions to the stock of knowledge. The questions that must be addressed by policy makers today therefore concern the identification of the set of preconditions which must be met if advanced materials and the rest of high technology industries are to conduct successful R&D and remain competitive in the world market. Market failure in the form, for example, of the public good nature of basic scientific endeavour, or "too slow" or "too little" direction of resources into complex, risky expensive, long run R&D, may undermine the growth of specific high technology and thus require corrective intervention and actions. Our discussion highlights the fact that the strategic and critical importance of advanced materials high technology activities provide a strong argument for a thorough re-examination of the proper domain and delimitation of the responsibilities of the government and the market in the scientific and technological realities of the 1990s. The technological linkages and externalities identified below further reinfore these arguments.

4.7.2 Advanced materials R&D and technology spillover effects

Knowledge generated in new materials R&D and synthesis and processing technologies can flow outside the firm assisting the R&D effort of a wide range of materials producing and using firms. R&D activities on final product and processes in user industries depends on R&D activities by materials producers and in many cases must be undertaken jointly and simultaneously. The production technologies of materials producers, users and equipment suppliers are mutually interdependent. Advanced materials and associated processing, measurement, characterisation technologies and standards stimulate and facilitate technical advance across the industrial spectrum. Technological breakthroughs or advances in specific technologies depend on the satisfactory development of a set of pre-existing and interdependent technologies and cumulative stocks of expertise and know how, many of which are materials related.

4.7.3 National or local technological interdependencies and R&D spillovers

High technology industries, are embedded in a national network of specialised materials and component suppliers (15,000 in the USA aerospace industry), academia, research institutes and centres of excellence, personal contacts and information networks, in mutually supportive roles. In turn, materials producers (and in-house materials R&D of users) are also deeply embedded in local and national networks of university, government and industrial R&D centres, information flows, personal relationships, professional societies, supporting infrastructure, technical and standards services and so on. Successful R&D in high technology depends on, reinforces and deepens the local or national accumulation of skills, know-how and specialised supplier bases. Successful materials R&D reinforces the local or national materials science and engineering infrastructure and promotes technical change across key high-technology sectors, which rely on state-of-the-art, knowledge intensive materials systems tailored to end use performance requirements. The decline or disappearance of the advanced materials supplier base entails the destruction of a broad range of scientific, engineering and processing know-how and thereby, the loss of competitiveness of high technology industries. The decline of high technology industries may erode the advanced materials infrastructure and supplier base, thus inhibiting future innovation and competitiveness of major segments of the manufacturing industry.

4.7.4 Successive trajectories of interdependent technologies

The historically accumulated domestic materials science, design, synthesis, characterisation and processing skills and know-how and the proliferation of a network of specialised supplier firms is crucial for facilitating the successful development of current technologies and the sequential development and mastery of next generation and related new technologies and industries in a process of dynamic adjustment of the industrial structure. It is doubtful whether economies in the 1990s can opt out of specific stages in complex and evolving technological trajectories and then easily re-enter at a later stage, in the 21st century having destroyed domestic skills, know-how and supplier networks.

4.7.5 Government policy support for materials basic research

Research and development in new materials is strongly rooted in advances in fundamental, frontier knowledge in the physical sciences. Government support is required in the provision of the basic scientific inputs which facilitate materials R&D of sophisticated and advanced materials systems to meet escalating performance requirements of user industries. Moreover, research into certain new materials can be of a long duration (10 years), expensive and risky. Here the government must support basic scientific endeavour and pre-commercial technology development at universities, government laboratories and private industry (directly or through fiscal incentives) and assist the formation of collaborative research between them. Moreover, it can provide the necessary scientific, metrology and instrumentation infrastructure plus standard and information dissemination to enable successful R&D and innovation to take place. These forms of government-industry-academia interactions not only orientate the scientific endeavour to industrial needs but, moreover, provide early competitive advantage to domestic clusters of interrelated firms and industries.

4.8 The USA Technology Policy: Commercial Reorientation of Federal R&D

4.8.1 Partnership between government and industry, commercialization of R&D

In February 1993 the new Clinton Administration unveiled its technology plan[23]. It acknowledges that technology acts as the engine of economic growth, underpinning up to two thirds of US productivity growth since the 1930s. Today, it argues, international competitiveness depends on new knowledge-based growth industries where continuous technical change is rapidly transformed into commercial products for the world market. Moreover, new best practice manufacturing technologies utilise energy and materials more efficiently and dramatically reduce environmental emissions and other forms of pollution. Hence the Administration wishes to promote technology as a catalyst for energy-efficient, environmentally compatible, high-skill, high wage, high employment, long run growth, by

1. Directly supporting the development, commercialisation and deployment of new technology;
2. Fiscal and regulatory policies that indirectly promote these activities;
3. Investment in education and training; and
4. Support for critical transportation and communication infrastructures.

With regard to item 1., the new Administration confirms the fact that the *defacto* US technology policy in the post-war period simply consisted of providing support for basic science and mission-orientated research conducted at NASA, the Defense Department and other agencies. In essence, it relied on defense and space-related R&D and technological innovation to spin-off or trickle down to civilian industry, while federal support for commercial technology was minimal. This approach is now seen as completely inappropriate in today's technological and world market conditions where the USA is facing serious challenges from economies with strong government support for commercial technologies. The plan therefore proposes a multifaceted strategy for government-industry cooperation in support of the development, commercialisation and use of new technology in private industry. The Administration plans to modify the *modus operandi* of Federal agencies in order to encourage much greater cooperation with industry in areas of mutual benefit. In this manner it is hoped that a far greater amount of federal R&D funds and research will be channelled towards (pre-competitive) research of commercial relevance, and where appropriate, the promotion of the broad application and diffusion of new technologies and associated know-how.

At the level of R&D and associated technological development, the main instrument for the new commercially orientated approach will be the cost-sharing R&D partnership between government and industry. All US Federal agencies and the 726 federal laboratories will be encouraged to form partnerships with industry, thereby meeting both government and industry needs. The new approach is especially relevant for the Department of Defense (DoD), which accounts for 56 per cent of all federal R&D. The already high number of dual-use projects at the DoD will increase significantly in the years to come. More specifically, in order to strengthen government-industry cooperation and provide more federal support for commercial R&D, the plan proposes:

- To increase the ratio of civilian and dual use R&D to purely military R&D (From 41:59 in 1993 to 50:50 by 1998, with civilian R&D spending rising from US$ 27.9 billion to US$ 36.6 billion respectively).
- To expand the Commerce Department's Advanced Technology Programme (ATP) significantly.
- To rename the Defense Advanced Projects Agency (DARPA) to Advanced Research Projects Agency (ARPA).
- To instigate new Department of Energy programmes designed to increase energy efficiency in industry, transportation and buildings and new renewable energy programmes.
- ALP, ARPA and other federal agencies to pay special attention to manufacturing R&D programmes. SEMATECH receives matching funds from DoD and will serve as a model for federal consortia funded to advance other critical technologies, eg. the development of a new automobile, new construction technologies, intelligent control and sensor technologies, rapid phototyping and environmentally conscious manufacturing.
- To review all federal laboratories managed by DoD, the Department of Energy and NASA, which can make a contribution to civilian technology with the aim of devoting at least 10-20 per cent of their budgets to R&D partnerships with industry.
- To ensure that federal agencies remove all obstacles to cooperative R&D agreements (CRADA's) and facilitate industry-laboratory cooperation through other means.
- To strengthen the Federal Coordinating Council for Science, Engineering, and Technology (FCCSET). (Initiatives are currently underway in advanced supercomputers and computer networks, mathematics and science education, materials processing, biotechnology, advanced manufacturing and research into climate systems understanding).

In commercialisation, both the reorientation of federal R&D and cooperative R&D programmes are seen as playing an important role, together with tax and regulatory reforms. Additional measures include the formation of Regional Technology Alliances and Agile Manufacturing Programmes. In terms of access and use of new technologies, programmes are proposed to ensure that all manufacturing firms, especially the 360,000 small- to medium-sized firms, have access to new technologies. This includes the creation of a national network of manufacturing extension centres, the expansion of manufacturing expertise in the classroom programme, and Department of Labour programmes to implement high performance work organisation principles.

The plan states that technical advances depend on basic research in science, mathematics and engineering. The US Federal government has invested substantial resources in basic research since the second world war, resulting in arguably the best network of centres of excellence in basic and fundamental research in the world. The aim of the Administration is to continue to provide strong support for basic research, stable funding for projects that require continuity and the setting of clear priorities in such funding. Programmes deemed as of a high priority will receive sustained support.

Given the importance of university research for long run scientific and technological capabilities, the adequate and sustained funding of university research grant programmes through the National Science Foundation and the National Institutes of Health is considered essential. However, national laboratories provide would class facilities in fields such as materials science, high-energy physics, biomedical science, nuclear physics and aeronautics for the use of researchers from universities, Federal laboratories and industry. Such laboratories will continue to be supported so as to enable them to maintain their key contribution to the conduct of basic research, while, at the same time, cooperative R&D programmes between the laboratories, universities and industry will be encouraged.

4.8.2 Information infrastructure

Bringing about a new technological revolution through the creation of a vast information infrastructure based on high-speed fibre-optic networks is the cornerstone of the Administration's strategy for revitalising the American economy into the next century. Greater efficiencies in the transmission and accessibility of information is crucial to all sector of the economy, and is increasingly providing the springboard for the creation of new business opportunities. Moreover, access to super computing power will have an enormous impact on the conduct of scientific research, the design of complex products and industrial processes and more efficient manufacturing operations, to name but a few. To this end, the Administration intends to implement the High-performance Computing and Communications Programme (established by the High-Performance Computing Act of 1991), create a Task Force on Information Infrastructure and an Information Infrastructure Technology Programme, and provide funding for networking pilot projects.

President Clinton is aiming[24] to spend US$ 4 billion over a four-year period to ensure the success of this project, and in this he is finding enthusiastic support from US industry. It is estimated that these "electronic highways" could generate up to US$ 3,500 million in revenue at the beginning of the century, a sum representing half of the nation's present GNP.

4.8.3 Government-industry R&D alliance for next generation automobiles

A striking new initiative was announced in October 1993 in which the government and the automobile industry would join in an R&D alliance to create an efficient and ecologically friendly vehicle for the 21st century. The aim of the partnership, that may cost billions of US dollars, is to produce a car that travels 80 miles to the gallon (the average for 1990 being 21 mpg in the USA), is safe, low-polluting and affordable. A prototype is to be build by the year 2003.

This approach highlights the shift in the Clinton Administration's new industrial policy. Here automotive engineers from General Motors, Ford and Chrysler will join scientists and engineers, previously working on defense projects, from government research laboratories such as Sandia in New Mexico and Lawrence Livermore in California. The research aim is to seek a replacement for the internal combustion engine. Initial efforts would focus on advanced catalysts for lean-burn engines, electrical-power systems and energy conservation via fly-wheels, ultracapacitors, new generation of batteries or new types of storage systems. Research will also focus on new generation light materials for the body structure, such as aluminium, polymer composites and graphite.

4.9 Japanese industrial policy: advanced materials, the national innovation system and high technology push in the 1980s and 1990s

4.9.1 The National Innovation System: from catching-up to pioneer of fontier technologies

Whereas the US research system has until recently, been dominated by an overwhelming emphasis and orientation towards defense-related R&D, and thereby reliance on commercial spin-offs, Japan faces no such burdens in the allocation of her scientific, engineering and financial resources, almost all of which could be channelled towards commercially driven R&D efforts. The US system, based on scientific excellence and orientated towards relevance for defence, has of recent been challenged by Japan, a latecomer successfully catching up in several technologies and industries in which the USA reigned supreme less than two decades ago. US research is currently attempting to respond and learn from the Japanese challenge, while the Japanese national R&D system is reorganising in response to the needs of frontier technologies and is learning from the inventiveness, creativity and research excellence associated with her European and US competitors. The stage is set for intense competition in high technology as several IAC's and NIE's are reforming their research system and linking it to the manufacturing base of their economies. The USA is unrivalled in basic scientific research, which is currently being redirected towards industrial needs, with a parallel and strong emphasis on building up manufacturing and engineering skills. The successful integration of US research with manufacturing skills will pose serious threats to Japanese industry in the future. On the other hand, Japan is, at present, unrivalled in manufacturing, and is currently building up her domestic and international R&D skills in order to be able to conduct original and state-of-the-art R&D in high technology, moving beyond imitator to creator[50] of new technologies.

As Okimoto (1989) points out, if the strength of the defense oriented US R&D system lies in its pioneering character, and in the creation and fostering of infant high-technology industries within the military R&D and government procurement complex,.."the strength of Japan's system lies in its capacity to convert breakthroughs in basic knowledge swiftly into tangible products on store shelves. Japan's commercially oriented and market-driven R&D system is based on painstaking consensus building, government-industry co-operation, an emphasis on advancing the not very glamorous but commercially decisive area of process technology, cost effective resource allocation, information sharing, technology diffusion, and a singularity of focus on commercial applications". (1989, p.67).

The Japanese emphasis on process technologies, manufacturing engineering and commercial application, in the context of *kaizen* activities, is of paramount significance. It forms a central part of the explanation of Japanese ability to catch up with front runners in several technologies and industries in the space of a generation. It is also bound to play an equally significant role in the next stage of industrial development based on next generation frontier technologies and the sequential development of successive generations of these.

It is crucially important to recognise that Japanese industrial policy[51] and the national R&D system were, until the late 1970s, directed towards catching-up with technologies pioneered elsewhere. However, objective economic and market conditions, such as the liberalisation of the economy, the state of development of existing technologies and competition from the NIE's, have forced Japan to shift from late comer to pioneer of frontier technologies, while retaining traditional strengths in process technologies. It is of course relatively easier to identify, enter, systematically develop, and catch-up and dominate pre-existing technologies, than to select a portfolio of promising new frontier technologies and engage in risky, expensive, original and complex fundamental and applied research with greatly uncertain outcomes on technological development and commercialisation. Not only is the technology foresight and selection process fraught with greater difficulties, but the national innovation system must be in possession of an inventive creativity, skills, know-how, resources and public and private centres of scientific excellence, which are the prerequisites for successful basic R&D underpinning and response to frontier technological developments. The nature and instruments therefore of Japanese industrial and technology policies have been responding to the new circumstances of the 1980s and 1990s. MITI has, for example, jettisoned the cruder set of industrial policy interventionist instruments employed in the earlier catch-up period (e.g. in automobiles, steel or semiconductors in the 1970s) since they became increasingly inappropriate to the requirements of high technology[52].

An important characteristic of high technology R&D is that it operates close to and depends upon frontier scientific knowledge. Without in-house basic scientific research capabilities and access to frontier knowledge, generated domestically and abroad, a firm will soon fall behind state-of-the-art R&D and its technology development will face limits from the side of fundamental knowledge (e.g., in the next generation quantum electronic devices). Given the "public good" nature of much of basic scientific research there arises the problem of who pays for it. Clearly the level of scientific endeavour may be socially suboptical in a market economy, especially since high technology firms already incurring heavy applied R&D expenditures and investment outlays in plant facilities may be unable or unwilling to finance upstream scientific research, which, none the less, may be crucial to future competitiveness of technologiesthat constantly push at the limits of knowledge.

Government has a clearly defined role in correcting for market failure in the level of basic research undertaken in an economy, through the direct funding or underwriting of the costs of basic research and/or the provision of fiscal incentives and the legal framework which would induce private corporation to commit their own funds to basic R&D. If invention and innovation in high technology depends on breakthroughs in fundamental scientific knowledge, but the latter retains the characteristics of an inexhaustible public good, which moreover is associated with ever increasing costs and uncertainties, then governments can and do directly intervene to improve social outcomes. However, it is not sufficient for government to simply underwrite the costs of basic research and then hope that somehow this finds its way into commercial application. A range of instruments can be employed, which ensure both a higher level of basic research undertaken and its transmission into applied R&D and commercialisation. That is, it is both a matter of supporting fundamental research and channelling it to or enabling it to respond to the needs of downstream applied R&D, technological development and commercialisation. Here, governments can promote[53] commercial R&D in high technology by offering fiscal incentives, facilitating or organising co-operative R&D projects, transfer technology from university and government laboratories to the private sector, eliminate duplication of the research effort, enable the attainment of research economies of scale and create the legal framework that facilitates inter-firm cooperation in pre-commercial research. Japanese industrial policy has been active in all these areas in response to what it perceives to be legitimate causes for government intervention (see Table 5). Given, for example, lifetime employment practices in Japanese industries technological spillover effects are impeded. This provides a strong rationale for government intervention to facilitate the greater diffusion of knowledge and technology across industrial firms. Collaborative R&D consortia and projects meet several of the criteria above.

Industrial policy to promote high technology includes macroeconomic fiscal and monetary measures conducive to the growth and health of such industries displaying high income elasticity of demand and the provision of appropriately skilled and technically proficient human resources. MITI has not been directly involved in influencing the educational system to assess the needs of industrial development. However, we must refer to an important consequence of MITI's industrial policy, namely the impact of "visions" of the long term evolution of the industrial structure, which exercises considerable influence on the choice of educational path and employment preferences of Japanese students. High-growth and strategic high technology sectors of the future tend to attract the best and brightest of Japan's graduates. Moreover, individual companies orientate their R&D and new business departments in line with these "visions" in order that they attract the cream[54] of university students, especially in science-related subjects.

We will not engage here in a detailed and historical examination of the extent and "fairness" or otherwise of MITI's industrial targeting and promotion of strategic industries through subsidies, infant industry protection, promotion of exports, "buy-Japanese" policies, etc. As Okimoto (1989) points out at length, MITI has indeed made several mistakes, and, a number of industries grew to world class standards without MITI's industrial targeting and infant nurturing. Indeed, industrial targeting is exercised in a variety of guises by governments around the world. Rather, given that Japan continues to select specific industries for promotion we will focus on more recent efforts to accelerate technical change in a series of high technology industries in so far as they relate to the concern of this chapter.

4.9.2 Technology push through national R&D projects

It is important to recognise that Japanese industrial policy attempts to predict and plan for technological and industrial life cycles. That is, MITI's "visions" for the future are informed by an in-depth consensual understanding of the lifecycle of specific technologies and an attempt to "plan" for the phasing out of obsolete technologies and the optimal phasing in of new generations of technology and indeed of radical technological revolutions. From very early on in the 1980s, several[55] high technology industries have been identified as providing the basis for the growth of the Japanese economy in the 1990s and into the 21st century. However, the arrival of Japanese industry to frontier technologies has necessitated that close attention be paid to the reorganisation and upgrading of Japan's basic research capabilities in order to meet the requirements of frontier innovators and pioneers. In order to correct for perceived scientific deficiencies and reorganise upstream basic research, the Japanese government has initiated a series of very ambitious national R&D projects aimed at catapulting Japan to the very frontiers and beyond of high technology, (for the current content of MITI's projects see insets below).

All national research projects in Japan conform to the criteria briefly mentioned earlier. The aim is to conduct basic precommercial research on technologies of seminal importance to the future of Japanese industry and society. In pursuing this goal, collaboration between firms and between firms, universities and the government is viewed as a necessary and sensible approach. The focus is on upstream basic research and pre-commercial generic technology development, which is too costly, risky and of such a long time horizon that individual firms will have too little incentive or resources to undertake if left to themselves. The government therefore steps in to encourage resources to flow into basic R&D in consonance with the collective needs of selected strategic or priority industries and of the economy as a whole. Common to all projects are the following elements:

1. Anticipated long gestation periods
2. The presence of a high degree of uncertainty and risk
3. Heavy R&D expenditures
4. The development of precommercial prototypes
5. The existence of economies of scale in research
6. The presence of steep learning curves
7. The potential for improvements in processing and manufacturing technologies
8. The potential for commercial application across a series of industries, and

9. The promise of large intersectoral multiplier effects on the economy[56].

4.9.3 National R&D projects benefit the economy in several ways

The provision of a "vision" of the future evolution of the industrial structure and the identification and selection of the relevant seminal technologies on which to organise national research projects and provide seed[57] money helps R&D departments of several companies to select research priorities. As is often the case in Japan, once a number of leading Japanese corporations decide to move along a specific technological path, many of the others will follow, so that the whole industry pursues a particular R&D and commercialisation objective with single minded determination, increasing the probability of success. Technological spillovers throughout the economy follow from the government practices of making most patents available to all companies on a non-discriminating basis. Further, national projects avoid wasteful duplication of the research effort by dividing up labour across institutions, while minimising the risk of crowding out research undertaken in company laboratories along parallel lines. Here, it must be stressed that national R&D projects in no way intend to replace corporate R&D. Rather they act so as to complement and enhance it. In fact, as we point out elsewhere in this study, corporate R&D laboratories have not only grown markedly in size and number, but have also overtaken public sector laboratories in terms of research capabilities. Most of the R&D effort in Japan today is still conducted by private company laboratories. The contribution of the national R&D projects is in the generation of pre-commercial generic technologies which companies can then exploit through applied R&D, technological development and commercialisation. The applied R&D and commercialisation stage is fiercely competitive between companies, and constitutes the main driving force and source of competitive advantage for Japanese companies in the global market place. This point highlights the fact that simply listing critical technologies and even organising[58] R&D projects, if at all feasible, around them, are not enough. The ability of Japanese companies to competitively commercialise technological breakthroughs through integrated applied R&D and manufacturing skills has played, and will continue to play, a determining role.

Given that several projects are still ongoing it is difficult to offer a conclusive or full verdict as to their importance or effectiveness. However, they appear to have made contributions on a wide front viewed by Okimoto to comprise of the following:

> *"1. Identifying the seminal technologies on which R&D cooperation can take place;*
>
> *2. Promoting extensive generation and exchange of information between industry, government, universities, and the financial community;*
>
> *3. Allocating more R&D expenditures and subsides for private companies, which are especially useful during cyclical downturns;*
>
> *4. Helping companies conduct themselves to the long term development of vital pre-commercial technologies;*

5. Transferring know-how from government to corporate laboratories;

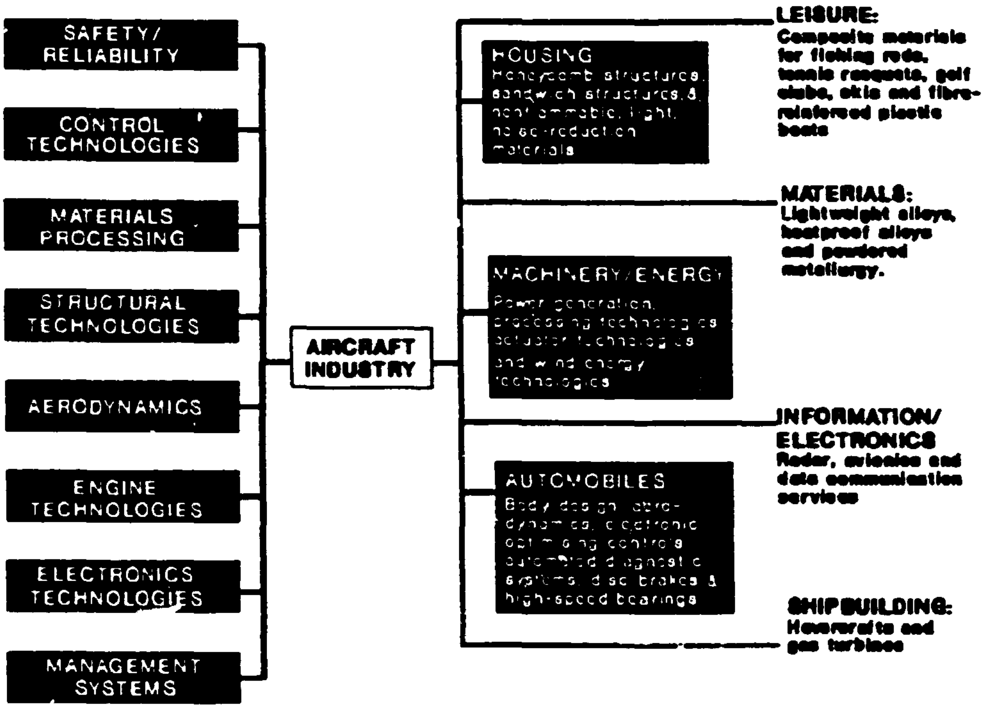
6. Encouraging and facilitating close contact amongst scientists and engineers;

7. Diffusing pre-commercial technology throughout an economy where career-long employment limits the speed and scope of diffusion; and

8. Equalising technological capabilities among leading firms and intensifying the need to develop new products and process technologies. Of these contributions the last four have been of particular importance". (1989, p72)

A final point here relates to MITI's capacity to chart future research directions in frontier technologies when it cannot draw from the success and failures of front runners. The penalties to industry from MITI's selection of wrong technologies or mechanisms for their attainment could be enormous. The likelihood though of picking the wrong technological paths is minimised by the very process of technology foresight and selection in which MITI is always engaged. In order to identify the future direction of technological evolution or revolutions and where the promising areas for commercialisation lie, MITI conducts very detailed discussions with private industry, scientists and engineers, academia and financial analysts, collecting the most up to date and thorough information available. The selection of the technological paths to be followed is a result of deeply informed and consensual approach in which private industry participates fully. The likelihood of failure is thereby minimised, but of course, not eliminated. Those who argue against the government being able to "pick winners" construct a "straw man", which bears no resemblance to the reality and complexity of the consensual and market-led industrial and technology policy formation in Japan, which may or may not be able to be emulated in different national settings in the West. But the latter is a different issue. Secondly, it is not clear that market forces left entirely to themselves could perform better in the selection and subsequent generation and commercialisation of new technologies, especially if, as we argue, government support is required at several stages of the R&D process. Thirdly, it is folly to expect MITI-type targeting of specific industries and associated technologies to always be successful and out perform commercialisation of the same technology abroad by firms subject to different or less direct relations with their government, the recent developments in HDTV being a prime example. To deduce from the faster USA and European technological development of HDTV that, erroneously the government cannot "pick winners", or that the "market", whatever that is in high technology, is always better or preferable or more efficient than a joint government-industry collaborative approach is not rational and can be dangerously misleading in the 1990s. Western industry can and will out perform Japanese industry in specific technologies. It does not mean that all of MITI's National Projects will fail[59] to deliver decisive commercial advantages and a headstart to Japanese industry in a range of technologies over the next ten years, or that western governments can afford to place complete reliance on markets to bring forth the same technologies. If we take the latter view, the almost complete lack of a science, technology and industrial policy and a heavy emphasis on the market in the UK over the last fourteen years ought to have resulted in a renaissance of manufacturing and the successful development of high-technology segments

INDUSTRIAL APPLICATIONS OF AVIATION TECHNOLOGIES



Source: **Business Tokyo**, February 1990.

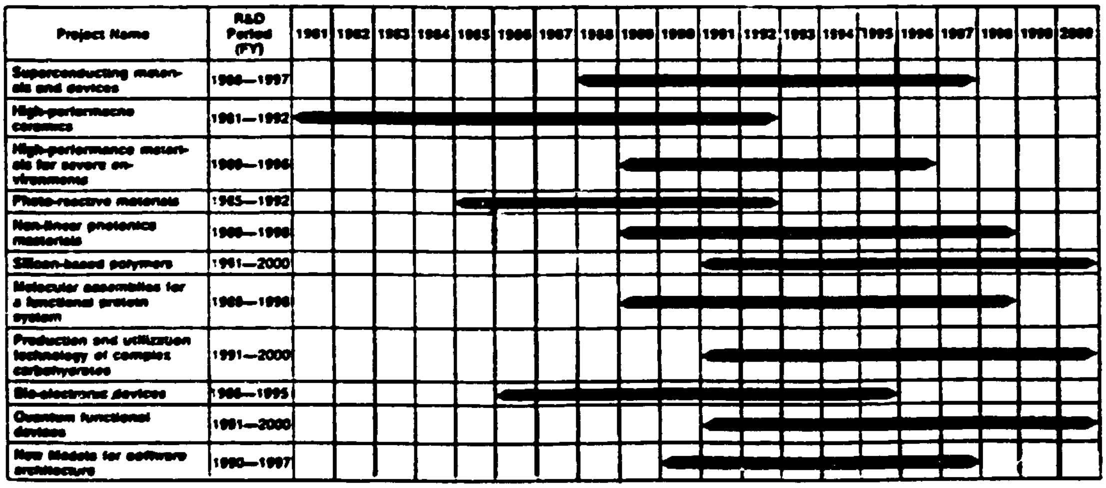
of industry (e.g. aerospace). Fourthly, the MITI (or AST) approach is not simply confined to the development of technologies with purely commercial application, but is rather far more broadly based in terms of identifying technologies that may have seminal socio-economic implications. Unless the government together with industry makes a committed, long-run R&D effort such technologies may never evolve. Or, it identifies serious health, environmental or energy problems that require solution. Again, if a joint industry-government long-run approach is not taken, the technological solution may never be obtained. If there are commercial rewards for such an endeavour (e.g. in environmental technologies), so much the better. Again, these considerations are absent in the narrowly defined can the government pick winners debate.

JISEDAI Programme Budgets, 1981 to 1992

(Unit: Million Yen)

Budget (FY) Field of R&D	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
Superconductivity	—	—	—	—	—	—	—	1.061	1.872	2.347	2.778	2,888
New materials	1.356	2.596	3.191	3.258	3.593	3.572	3.538	3.144	2.807	3.806	3.911	3,403
Biotechnology	675	1.043	1.191	1.201	1.252	1.220	1.085	938	817	472	557	790
New electron devices	673	1.128	1.451	1.478	1.585	1.542	1.404	1.209	1.311	766	320	793
Software	—	—	—	—	—	—	—	—	—	53	270	283
Total	2.714	4.786	5.850	5.952	6.445	6.513	6.043	6.368	6.836	7.463	7.866	8,773
Year-to-year Increase/ Decrease (%)	—	+76.3	+22.2	+1.8	+8.3	+1.1	−7.2	+5.4	+7.3	+9.2	+5.4	+3.9

Long-term Projects



THE R&D PROGRAMME ON BASIC TECHNOLOGIES FOR FUTURE INDUSTRIES

(JISEDAI PROGRAMME)

Research and Development Programme on Basic Technologies for Future Industries (JiseResearch and Development Programme on Basic Technologies for Future Industries (Jisedai Programme) was initiated in 1981 by MITI as part of a national industrial policy designed to promote R&D in innovative basic technologies deemed indispensable for the next generation of industries in aerospace, information technologies and biotechnology, as well as upgrade a broad range of existing industries. Whereas in the previous stage of industrial development the emphasis was on the application and development of pre-existing and globally available invention and technology, it is widely recognised that Japan must now promote the indigenous research and development of fundamental technologies which would underpin the emergence of a new generation of industries in the context of a growing and evolving industrial structure into the next century.

It must be emphasised that the selection, implementation and evaluation of the national R&D projects is undertaken through a trilateral framework involving very close and meticulous cooperation between MITI, the national research institutes (under MITI's Agency of Industrial Science and Technology, AIST), universities and private industry. The criteria for selection involved the following elements :

i. These basic, but extensively innovative technologies, will have major and far reaching effects as they diffuse in a wide range of industries with large intersectoral linkages in the economy.

ii. R&D on these technologies generally requires the commitment of very large sums for long periods of time (on an average ten years) with uncertain outcomes and commercialisation prospects. They are therefore too expensive, complex and risky for individual private corporations to undertake on their own.

iii. They involve basic technologies with potential applications at some time in the future.

In addition to the three explicit criteria above, it is recognised that R&D in the selected basic technologies will have beneficial technology spillover effects in the global community consistent with the present stage of economic development and expectations regarding Japan's contribution to basic and applied research. Due to their importance and scope, the projects have attracted international interest, and benefits are expected to flow from Japan through international exchanges and joint research.

JISEDAI PROGRAMME ORGANISATION

MITI

Industrial Development Council
Next generation Technology Development Committee

Planning Office of Basic Technology for Future Industries
(Agency of Industrial Science and Technology)

Promotion Committee
Coordinator

Evaluation Committee

National Research Institutes

New Energy and Industrial
Technology Organisation (NEDO)

R&D laboratories of private
firms and university R&D

The R&D method employs a parallel system whereby research and development activities are simultaneously pursued at a number of participating research institutions. For each theme a 'Basic R&D Plan' is established with preset development targets in order to monitor progress and evaluate results over the ten-year period. Projects are assigned to national research institutes while other projects are contracted through NEDO to private corporations and universities on a merit basis.

MITI's Next Generation Industrial Technology Planning Office promotes the JISEDAI Programme and coordinates it with industrial policies. The Industrial Technology Council discusses the Basic R&D Plan set over a ten-year period, while the Promotion Committee coordinates and discusses at research implementation level the ongoing R&D projects at government and private research laboratories. R&D coordinators provide a long-term guidance and direct R&D projects.

In FY 1992, there were eleven ongoing R&D projects as shown below in five fields: superconductivity, new materials, biotechnology, new electron devices and software.

As of the end of FY 1991, 602 patents were issued, and 9,773 research results presented to the public, including papers presented in Japan and abroad. The JISEDAI Industrial Basic Technology Symposium is the main instrument for the presentation of research results on a yearly basis and is open to the public.

LIST OF NATIONAL R&D PROJECTS FY 1992

Fields	Subjects
Superconductivity (one project)	Superconducting materials and devices
New Materials (five projects)	High performance ceramics High performance materials for severe environments Photo-reactive materials Non-linear photonic materials Silicon-based polymers
Biotechnology (two projects)	Molecular assemblies for a functional protein system Production and utlization technology of complex carbohydrates
New electron devices (two projects)	Bio-electronics devices Quantum functional devices
Software (one project)	New models for software architecture

The case study on the Japanese National R&D Project on High-Temperature Materials illustrates the close interdependence between the development of high-technology industries of the future and solutions offered from the side of materials science and engineering. Industrial policy must increasingly coordinate with materials policy in delineating the advanced materials technologies required for next generation industries, and the new materials with the greatest potential for the creation of new industries and/or resolution of energy/environmental/societal needs. However, many of the new materials designed for exceedingly high performance requirement can only be arrived at through persistent, risky and expensive R&D efforts over a long time horizon. It is here that government intervention attempts to correct for market failure through the supply of the scientific infrastructure and finance, the provision of fiscal incentives for more private research effort and the bringing together of universities, government laboratories and industry in conducting generic or pre-competitive basic research, which might otherwise not be forthcoming if reliance were placed on market forces alone. This collaborative research on generic technologies facilities the transmission of new knowledge to commercial applications, provides a head-start to domestic firms, leads to the diffusion of new technologies in the industrial base and provides essential inputs to in-house applied R&D and commercialisation of new technologies by fiercely competing firms. It must be stressed that the R&D projects place considerable emphasis on the development of processing technologies and standards.

R&D PROJECT ON HIGH-PERFORMANCE MATERIALS FOR SEVERE ENVIRONMENTS – 1989 to 1996

Several R&D projects are being implemented or studied which relate to technologies at ultra-high temperatures. The aims of the projects is to promote next generation technologies and industries for the 21st century, including aerospace [(the development of space planes, supersonic transport systems (SST's), HyperSonic systems (HST's)], energy resource development of coal gasification power generation systems and nuclear fusion reactors, and new materials manufacturing processes and equipment. Achieving these industrial, energy and environmental objectives requires the development of next generation ultra-high temperature materials with projectiles and performance characteristics not attained by existing materials. The new materials must be exceptionally light, possess enormous strength and must be able to function in environments with severe oxidation and corrosion, and where temperatures may reach as high as 2,000°C.

This R&D project therefore aims to develop technologies for advanced lightweight structural materials capable of withstanding severe environments, exhibiting superlative specific strength and rigidity, resistance to thermal shocks, thermal fatigue and oxidation, and in particular, capable of withstanding temperatures as high as 1,000 to 2,000°C, for use in aerospace, energy generation and manufacturing equipment. Today, the typical heat-resistance structural materials for high temperature application (e.g. jet engines) are iron-based, nickel-based and cobalt-base superalloys. Despite the successful application of computer-aided alloy design and the development of a single-crystal turbine blade alloy in Japan, it is difficult to improve the temperature capability of nickel-based alloys to 1,300°C, even with the addition of alloying elements, the reinforcement of tungsten fibre or a plasma sprayed thermal barrier coating. Other classes of materials are expected to surpass superalloys in heat-resistance. In metallic materials, alloys of intermetallic compounds and refractory metal; in composite materials, carbon/carbon (C/C) and ceramic matrix composites (CMC); and from ceramic materials, non-oxide ceramics such as sialon, Sic and Si_3N_4.

R&D Targets: To establish the basic technologies for the development of intermetallic compounds with excellent isotropic strength, oxidation resistance and toughness in high temperature environments, and advanced materials capable of withstanding severe environments and possessing excellent heat resistance and specific strength at high temperatures. The project aims to develop the following materials:

1. Intermetallic compounds

- High Specific Strength Intermetallic compounds.
  Compounds with a specific strength (strength/specific gravity) of over 100MPa at 1,100°0C, and elongation of over 3 per cent at room temperature.

Target material: The target for development here is a T_i Al-based intermetallic compound.

Manufacturing processes: A T_i Al thin plate manufacturing process (sheet casting and isothermal rolling processing). Another is near net shape forming using powder injection moulding.

- High Melting Point Intermetallic Compounds.
  Compounds with a tensile strength of over 75MPa at 1,800°C, and elongation of over 3 per cent at room temperature.

  Target materials: The niobium-aluminium (Nb-Al) system was selected as the target here.

  Processing techniques: A precision casting technique and an alloying powder preparation technique.

2. Development of advanced composite materials

- Carbon/Carbon Composites (Fibre Lay-up 2D). Composite materials which retain the following mechanical properties after heating for 20 hours in air at 2,000°0C.
  Tensile strength of over 700MPa.
  Tensile elasticity of over 200 GPa.
  Composite materials retaining such mechanical properties after heating for 200 hours in air at 1,800 C.
  Materials studied: five types of carbon fibre, three petroleum-pitch based, one coal tar pitch-based and one PAN-based are under research in the four categories of:
  - i. Performance improvement of carbon fibres (petroleum pitch-based).
  - ii. Improvement of matrix (oxidisation inhibition and improvement of carbonisation yield).
  - iii. New composite fabrication technologies such as pressurised resin char method, chemical vapour infiltration method, high-pressure impregnation carbonisation method and composite rod forming method.
  - iv. Oxidation resistant coating technology.
- Fibre-Reinforced Intermetallic Compound Composite Materials. (Fibre Lay-up)
  Materials with the following properties at 1,100 C:

  Tensile strength of over 1,200 MPa.
  Tensile elasticity of over 180 GPa.

  Materials retaining these mechanical properties after heating for 200 hrs in air at 1,100°C
  Materials: Research on the use of the high specific strength T_iA1 under 1 above in parallel with a S_iC fibre/T_iAl-based intermetallic compound composite material. Specific strength and specific stiffness of the composite material are to be strengthened by improving the fibre reinforcement.

Research is under:

i. Development of high performance (heat resistant, high-strength, oxidation-resistant) silicon carbide-based fibres.

ii. Improvement of compatibility between fibres and matrices.

iii. Development of composite fabrication technology.

3. Evaluation Technology

- Little data exist on evaluation of material characteristics at an ultra-high temperature environment. Consequently evaluation technologies must be developed. These include the measurement of thermal properties at high temperature and technologies for evaluating the mechanical properties and corrosion-and oxidation-resistances at high temperatures.

Anticipated Effects

1. Aerospace: The development of high performance structural materials for severe environments is expected to greatly enhance the feasibility of Space Shuttle re-entry vehicles, SST's and HST's.
2. Energy generation: Advanced materials with excellent heat resistance, radiation resistance and other severe environment resistance are expected to lead to new innovative designs, reliability improvement and automation of processes in the energy field, including coal gasification power generation systems, nuclear power reactors and nuclear fusion.
3. Materials processing industries: Advanced materials resisting severe environments are expected to enhance the performance and reliability of materials processing and manufacturing itself such as ultra-high temperature furnaces, smelting furnaces, hot presses and hot isostatic presses (HIPs). This in turn, will promote materials processing industries and will lead to greatly improved high performance materials.

R&D Set-up and Schedule

The research project began in February 1989 and covers an eight-year period to completion. It involves R&D at six research institutes and laboratories of AIST, nine private companies, eight laboratories of the Petroleum Energy Centre (PEC) of the R&D Institute of Metals and Composites for Future Industries commissioned by NEDO, with four universities cooperating on common basic technologies. The first four years involve basic studies on the selected materials and processes and the last four years involve the establishment of the relevant materials, processing and evaluation technologies.

4.10 Science and technology infrastructure

Today technology provides the main weapon for competitive advantage, environmental compatibility and long run growth. However, the generation, successful commercialisation and diffusion of new technologies is a very complex process, far more so than in earlier periods, requiring the timely provision of inputs and information flows from a diverse number of private and public sources. New technologies such as HDTV, optoelectronics, photonics, superconductors and so on, are extremely complex and require far-sighted public intervention in the form of a supporting scientific, technological and informational infrastructure, which is in-place and is able to create new relevant knowledge in response to emerging industrial needs and facilitate its speedy and efficient diffusion throughout the industrial base.

Schedule of Long-Term R&D Projects

Research Theme		1989 1990 1991 1992	1993 1994 1995 1996
Development of Intermetallic Compounds	Development of high specific strength intermetallic compounds	Development of material design, manufacture and processing technologies	Establishment of technologies for better material design, material manufacture and processing
	Development of high melting point intermetallic compounds	Basic studies on material design, material manufacture and processing technologies	Establishment of technologies for material design, material manufacture and processing
Development of Advanced Composite Materials	Development of heat-resistant reinforcing fibers	Development of heat resistant reinforcing fibers and basic studies on surface coating technology	Improvement of heat-resistant reinforcing fibers and establishment of surface coating technology
	Carbon/carbon composite	Development of matrix, basic studies on fabrication technologies, basic studies on coating technology	Improvement of matrix, establishment of fabrication technology, establishment of coating technology
	Fiber-reinforced intermetallic compound composite	Basic studies on interfacial reaction control, basic studies on fabrication technology	Establishment of interfacial reaction control technology, establishment of fabrication technology
Development of evaluation technology, material evaluation		Basic studies on technology for evaluating thermal, mechanical and chemical properties	Establishment of technology for evaluating thermal, mechanical and chemical properties, material evaluation

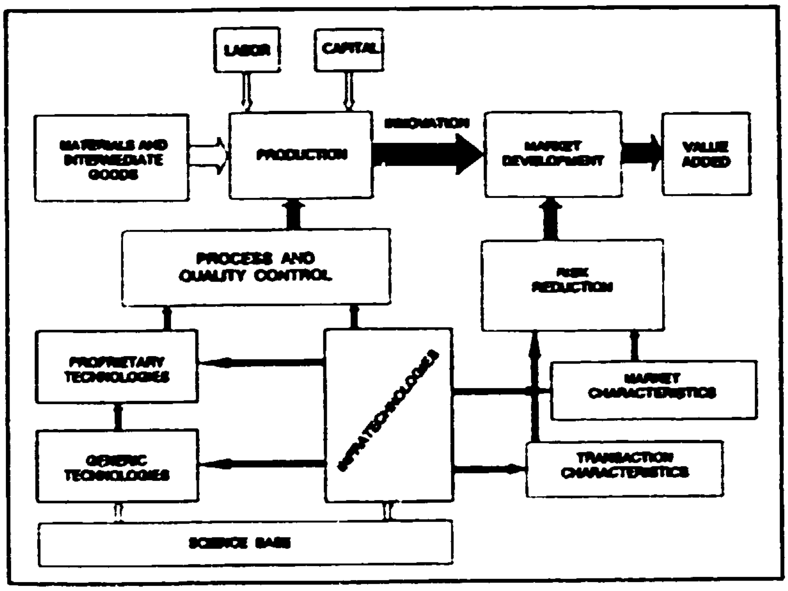
In an important recent contribution Gregory Tassey[60], formerly of the US Department of Commerce, identifies three areas where government intervention can increasingly correct for market failure:

1. **Early-phase R&D**
   Here, government laboratories and the formation of government-industry research consortia can facilitate and accelerate the conduct of generic technology research up to the applied R&D phase in several technologies such as computers, software,

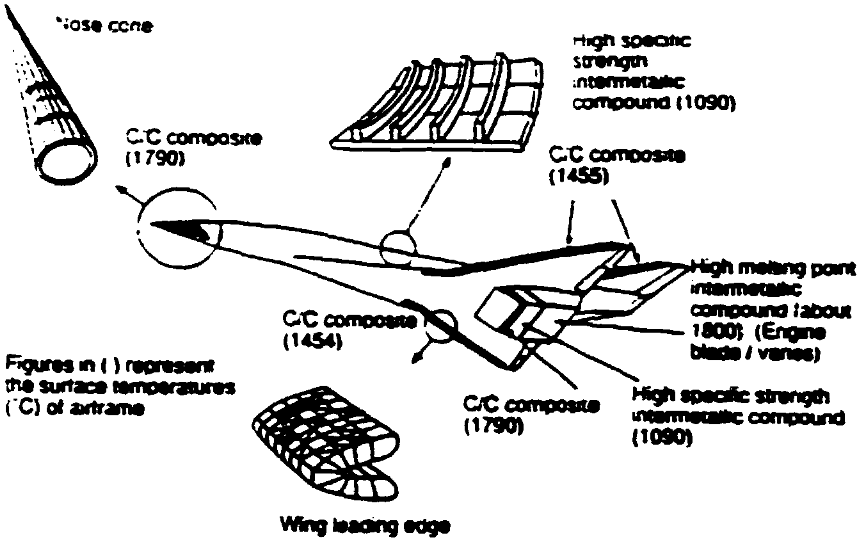
electronic components, superconductivity, advanced materials, robotics, machine tools and so on. he enhanced efficiency of early phase generic R&D shortens technology life cycles without adverse impact on costs. New generic technologies thus become available much earlier to domestic industry, which is then able to decide on specific applications, conduct private applied R&D and commercialise faster than competitors.

2. **Commercialisation of new technologies:**
   The efficiency and speed of technology transfer and diffusion, hence competitiveness of industries and economies, is greatly assisted by government institutions, mechanisms and schemes such as government laboratories, research institutes, transfer centres, government-industry cooperative programmes, national extensions services, and trade associations.

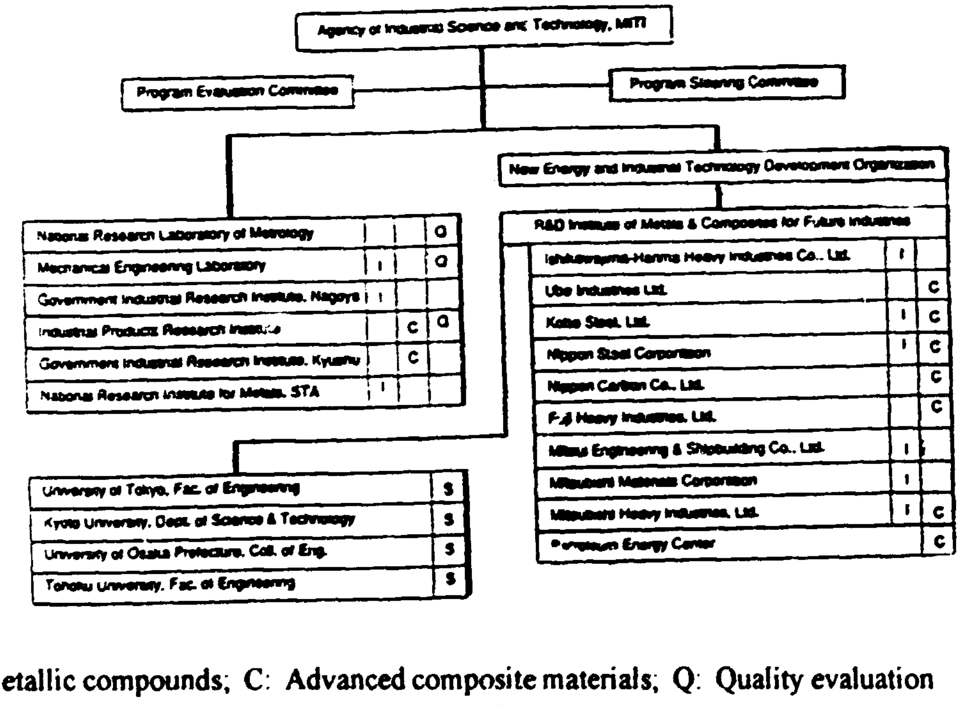
Disaggregated Technology Model



Examples of the Application of Advanced Materials for Severe Environments to Space Shuttle Vehicles



Functional Organization of R&D on High-performance Materials for Severe Environments



National Research Laboratory of Metrology			Q
Mechanical Engineering Laboratory	I		Q
Government Industrial Research Institute, Nagoya	I		
Industrial Products Research Institute		C	Q
Government Industrial Research Institute, Kyushu		C	
National Research Institute for Metals, STA	I		

University of Tokyo, Fac. of Engineering	S
Kyoto University, Dept. of Science & Technology	S
University of Osaka Prefecture, Coll. of Eng.	S
Tohoku University, Fac. of Engineering	S

Ishikawajima-Harima Heavy Industries Co., Ltd.	I	
Ube Industries Ltd.		C
Kobe Steel, Ltd.	I	C
Nippon Steel Corporation	I	C
Nippon Carbon Co., Ltd.		C
Fuji Heavy Industries, Ltd.		C
Mitsui Engineering & Shipbuilding Co., Ltd.	I	
Mitsubishi Materials Corporation	I	
Mitsubishi Heavy Industries, Ltd.	I	C
Petroleum Energy Center		C

I: Intermetallic compounds; C: Advanced composite materials; Q: Quality evaluation technology; S: Environmental science and technology.

Source: **JETRO**, December 1991

3. **Market development:**
   Government programmes to enhance productivity and quality and the provision of standards and measurement technologies enables companies to move beyond initial commercialisation of a new technology, penetrate the world market at the expense of foreign competitors and expand market share.

Furthermore, Tassey points out that contrary to the early "Black Box" view of the process by which industrial technology is created as a single economic activity, today technology-based world market competitiveness contains several interrelated but distinct components: Product technologies; process technologies; supporting infrastructure technologies; and complex sophisticated manufacturing practices so that new technologies can be utilised more effectively.

Product and process technologies have received much government and industry attention in several reports. Infrastructure technologies (Infra technologies) comprise of measurement methods, test methods, science and engineering data, standards and other information of a pervasive and critical importance to industrial technologies. Infratechnologies, as defined by Tassey, are in essence non-proprietary, and are not embodied in a product in the same way the core generic technology is. However, they are crucial for the development, manufacturing and application of the core technology:

1. **The conduct of basic and applied R&D:**
   Ultra precise measurement and testing technologies and organised, evaluated scientific and engineering data are essential for the understanding, characterising and interpreting research findings and hence the efficient conduct of each phase of R&D.

2. **Efficient manufacturing techniques:**
   The existence of extreme environment and ultra-precise measurement and sensor technologies enables greater control of manufacturing processes resulting in higher quality, more reliable and lowest cost output.

3. **Market development and commercialisation of new technologies:**
   Measurement and testing techniques and widely acceptable standards ensure the meeting of performances levels and facilitate market acceptance and diffusion of new technologically sophisticated products and processes.

The economic impact of infratechnologies although pervasive is only recently receiving the attention it deserves. By its very "public good" nature, complexity and ubiquitness, it is an area requiring the visible hand of government intervention through government standards laboratories (e.g. the NIST in the USA or the NPL in the UK) and cooperative R&D programmes subsequently disseminated to industry as relevant standards. The last component, namely sophisticated manufacturing practices, has recently been recognised as crucial, since it provides the overall framework and market strategy enabling product, process and infratechnologies to be developed and effectively utilised for competitive advantage. Many of those concerns can also be identified in recent policy discussions in the USA[61].

5. THE CRUCIAL IMPORTANCE OF MATERIALS PROCESSING AND MANUFACTURING ENGINEERING

5.1 Manufacturing engineering and processing skills

Japan's Economic Planning Agency in a comprehensive report entitled, "A Technology Forecast for the 21st Century" (July 1991), evaluated 110 critical technologies and came to the conclusion that it significantly lags behind the USA in many of those. Japan only leads in 33 technologies, with evident strengths in automation, electronics and transportation. Its lead though, is in areas with the greatest potential for commercialisation and market size. Out of 17 technologies which could lead to a market size of more than US$ 7 billion sales per annum in Japan, 13 are located in electronics, with memory devices, HDTV and optical communications potentially capturing market sizes of US$ 22 billion per annum. The USA is seen to be ahead in 43 technologies, with considerable strengths in energy, pharmaceuticals, the environment, and surprisingly, in new materials. The USA is considered by Japanese experts to be far ahead of Japan in the development of new material such as ceramic gas turbines, materials for high speed semiconductors and advanced metals.

On the other hand, the National Critical Technologies Panel points to the crucially important fact that Japan has long laid strong emphasis on materials process technologies, which has been the determining factor in superior Japanese world-class performance in several industries. The erosion of the US microelectronics and semiconductor[62] industries stems in fact from the superior Japanese materials processing and manufacturing skills especially in high volume processes essential to competitive success. US scientists are viewed as traditionally concentrating on examining the properties of novel materials, rather than their synthesis and processing, as is the case with Japanese and, recently, Korean and Taiwanese, practice. The findings of this book offer strong confirmation of such a view[63] and a warning that the potential exists of even worse consequences to follow for western industry in the years to come.

The emphasis on materials synthesis and processing technologies, both in traditional materials as well as new materials, and the strong orientation towards commercial application in the context of *Kaizen* (continuous improvement) techniques in product and process development has been a major factor in creating and maintaining Japanese world class competitiveness in many industries. Despite the relative superiority of the USA or Europe in a range of new materials research, and in some cases, application[64], it is more than likely that Japan will ultimately lead in the commercialisation of several key new materials technologies, including superconductors from the late 1990s onwards. The facts are as follows: Japan possesses traditional strengths in materials processing and manufacturing. Engineering skills abound in both activities, with finite element analysis playing an earlier and more important role in engineering design than in other countries. Engineers, moreover, rotate through design and manufacturing operations, obtaining all-round skills, thereby implementing simultaneous engineering with greater ease and on a far wider scale than western industry, where the idea is only now tentatively taking root. Moreover, quality assurance, continuous improvement[65], and integrated manufacture have long underpinned the rise of many Japanese firms to world class manufacturing standards since the late 1970s.

5.2 Firms domain in materials processing and their commercial application

New materials, biotechnologies and micro-electronics (including opto-electronics, mechatronics and opto-mechanics) have been identified and targeted early on in the 1980s as three critical or key enabling technologies, which would facilitate the restructuring of Japanese industry to high technology into the next century. The evidence on the ground points to a very clear understanding by both corporate senior and middle-management and government officials as to the crucial role of advanced materials technologies in underpinning competitiveness and growth, and a long-term view is taken of commercialisation of such technologies. After an initial flurry of activity and experimentation with novel materials by many firms in the mid-1980s, and some revision of expectations, the emphasis in the last three years is on processing and commercial application of materials already developed. The economic difficulties of 1991-1993 have put further strain on new materials departments and diversification strategies of many firms. But it would be a dangerous folly to conclude from this partial curtailment of activities, that Japanese firms have lost interest or abandoned new materials. Quite the reverse. One reason for the massive entry into new materials was the economic slowdown and Yen appreciation in 1985. The current difficulties are likely to lead to accelerated efforts at technological application and commercialisation of selected key materials within each firm's domain and traditional strengths, and showing the greatest commercial promise, only now with the advantage of several years experience and trial and error in the field. Indeed this is confirmed by recent evidence that a number of the large steel producers, facing serious difficulties in the first nine months of 1993, are focusing on new materials as an important component of efforts to improve sales and market prospects through the opening up of new business opportunities[66].

Strong government-industry institutional linkages exist in pre-competitive research. Where the technology is risky, expensive but crucial, or very promising for long term development, it is promoted at government laboratories, belonging to MITI's AIST and AST. In addition, financial support is provided through the Japan Key Technology Centre to inter-firm consortia exploring pre-competitive research in materials technologies with more immediate prospects at commercialisation.

It is not widely recognised that industry and academia play a central role in the identification[67] of key technologies through a process of consultation and consensus. Moreover, strong institutional linkages, networks and collaborative mechanisms exist between materials producers, users and equipment suppliers, as for example, in ceramics. This reinforces the speedy transmission of new materials developments into commercial application.

In all, the undoubted engineering skills in materials processing and across the manufacturing base, the recognition of the critical importance of new materials, the emphasis on processing and commercial application, the recent concentration on a narrow range of in-house technological competencies and commercialisation of new materials, and the strong linkages between government-industry research and development, would most likely confer decisive advantages to Japanese industry in the late 1990s and beyond. In fact, despite current economic and financial difficulties and short-comings in basic research, Japan is likely to conquer several materials dependent high technology fields in the years to come, while western economies continue to debate the merits of an 'industrial policy'. More than this, the integration of new materials into product and manufacturing process design will almost certainly confer even more decisive advantage to Japanese world class manufacturers in industry after industry. The new materials programmes of the leading Japanese car producers and their close collaborative alliances with first tier materials and component suppliers are richly instructive as to what the future is likely to bring. However, Japanese government officials and industrialists are possessed by a far greater degree of self-doubt, critical appraisal of their capabilities, and hence continuous improvement (see below), than the perhaps inordinately optimistic scenario advanced above. Both Europe and the USA are beginning to offer serious responses to the Japanese challenge so that there is nothing inevitable in the argument or prognostication.

6. THE GLOBAL RESTRUCTURING OF INDUSTRY 1980s – 1990s

6.1 Basic industries

Over the last two decades, basic industries in advanced industrialised economies (IACs) and less so in NIEs, have been undergoing fundamental restructuring[68], in which national industrial structures and economies are gradually shifting from a 'metals base' to a 'materials base'[69]. Traditional mono-material chemical, metals and ceramic firms are evolving towards large, materials multinational corporations (MNCs) accessing fast changing materials technologies globally, entering into cross-border strategic alliances and are characterised by strong customer orientation and increasingly, the establishment of local production facilities and/or R&D and technical support centres. Firms are beginning to acquire the necessary multi-disciplinary and multi-materials competencies through both internal strategic and external cross-border acquisitions, joint ventures, licensing agreements and technology networking and alliances, in a manner broadly similar to the observable tendencies in biotechnology, microelectronics and telecommunications.

Many firms in traditional industries such as steel, aluminum, copper, petrochemicals, chemicals, glass and ceramics within Japan, the USA, North America and some NIEs, have been reducing their dependence on or abandoning commodity materials production, while moving towards knowledge-intensive, higher value-added specialties and diversifying into new materials. The materials revolution is thus playing a central role in the internal transformation, restructuring and strategic orientation of basic materials producing industries. At the same time, it is exercising considerable influence on the demand prospects of traditional commodity metals and chemicals, which we cannot at the moment quantify with any certainty. What is clear is that initial concerns as to the "death of mining"[70] or the demise of traditional metals have been premature. Traditional ores and metals retain considerable importance and are, indeed, fighting back the challenge from new materials, through incorporating the insights of MSE to improve processing technologies and associated properties and forging close linkages with customers in specific market segments. Indeed, traditional metals are themselves being incorporated into new laminate and composite systems (as in metals matrix composites) or transformed into advanced metals, such as the new generation of steels.

Large portions of traditional mining and 'smokestack' basic commodity industries continue to be retained within IACs in many cases, as in copper, steel and aluminium, displaying dramatic gains in productivity through technological modernisation and rationalisation programmes instigated in the 1980s. This illustrates the critical importance of advanced processing and fabrication technologies in the 1990s as determinants of comparative advantage and geographic distribution of sources of raw and processed commodity materials. Nevertheless, the share of IACs in world mining and processing of commodity materials is declining, pointing to continuing and in some cases, rising import dependence[71]. Extractive, processing and refining stages of materials production continue to shift to regions and countries offering richer mineral concentrations, cheaper energy inputs, including hydroelectric and natural gas, and less restrictive environmental regulations. Nonetheless, commodity production of chemicals and metals will be subject to fierce competitive pressures on the basis of cost, quality, delivery and hence the application of advanced processing (including intelligent processing) and manufacturing techniques by private and public sector firms remaining in these upstream activities.

The onset of advanced materials is having important consequences for those elements of the periodic table that are finding useful applications. This is changing the relative importance of the constituents of the global resource base and the geographic sources of inputs such as rare earths, niobium or quartz. However abundant raw building blocks of advanced materials might be, a major feature of the new era is the shifting of import dependence experienced today by all major economies onto critical processed advanced materials, powders, fibres and components entering sophisticated technologies and engineering systems. This is likely to increase in the future. Another interesting[72] scenario concerns the potential ascendency of (high performance) plastics, environmental constraints permitting, within the materials field. This, of course, will increase dependence on the already limited supply of organic raw materials. This scenario though increasingly depends on the development of environmentally compatible, disposable and recyclable advanced polymers and associated recycling industries.

6.2 New best-practice manufacturing technologies

The restructuring of basic industries is closely related to and forms an integral part of the transition of industry in IACs towards new patterns of organising and managing production and, more recently, the employment of flexible microelectronics based automation technologies, across both new and declining or traditional manufacturing industries. The adoption of JIT organisational change, flatter managerial structures, responsible autonomy and multi-skilling at the shop-floor, and flexible automation technologies is a rational response to a fast changing market environment, when compared with the mass production, mass consumption Fordist paradigm of industrial organisation for most of the post-war period. Firms must increasingly compete in a business environment characterised by globalisation of markets and production, an intensification of competition, faster product renewal, the emergence of a quality and innovative design on par with price as determinants of consumer choice, the fragmentation of demand patterns, an increasing need to get close to the customer, and the need for a flexible and fast market response. Such developments have altered the determinants of foreign investment, technology and trade flows, and the locational patterns for manufacturing activity in traditional versus emerging centres and has led to new innovative forms of cross-border investments[73]. This study, on the other hand, points to the fact that the transformations in both the traditional and new advanced materials and the higher quality and performance requirements in user industries are already introducing a major new determinant in the relocation of industries[74], investment flows, trade patterns, inter-firm strategic alliances, technology transfer and marketing strategies. This is no more evident than in the complex redivision of labour currently underway in East Asia.

7. TECHNOLOGICAL LEADERSHIP AND COMPETITIVE ADVANTAGE IN THE 1990s

7.1 The role of advanced materials

Technological leadership and competitive advantage in the 1990s will, to a very large extent, depend on the domestic possession of a critical mass of advanced and improved traditional materials synthesis and processing capabilities. Japan is well on its way to attaining technological leadership in an increasing array of industries through its long run, meticulous promotion of advanced materials synthesis, production and commercial application. There are enormous and cumulative gains to be made in learning by producing and using advanced materials and late entry may either be impossible or subject to severe penalties. Several hundred Japanese companies entered new materials production and use from the early to mid-1980s, with a strong emphasis on a narrow range of extant technological strengths and commercialisation from the late 1980s onwards.

But more than this, a central message of this study is the idea that the next source of competitive advantage in the global market place resides in the incorporation of new materials in integrated manufacture[75]. Manufacturing industry is itself undergoing fundamental change, with several new concepts entering competitive strategy in the 1980s and 1990s. Efficiency standards are set by world class manufacturing competitors. The globalisation of industries has meant that there is no hiding place behind national market barriers in the face of an evidently intensified competitive pressure. At the same time, performance standards are set by companies with fast turnovers of inventory, offering higher quality, lower cost, fast product renewal, greater variety, and faster market response than their competitors. In this systemic combination of advances in information technologies, manufacturing technology and management practices, design for manufacture or simultaneous engineering, integrating all the functions of the corporation, provides the foundations for sustained and time-based[76] competitive advantage. **Nevertheless it is the case that the incorporation of new materials into product and process design in manufacturing is not only a necessity but a weapon of critical importance in conferring sustained competitive advantage in world class manufacturing.** The manufacturers will increasingly face the formidable challenge of Japanese and other Far Eastern world class manufacturers making use of the vast potential and options offered by the utilisation of new materials in integrated manufacture.

7.2 New materials technology: crucial potential for long term growth

Both government and industry in Japan have a very clear understanding of the role of technology for sustained competitive advantage and long run growth. Since the early 1980s advanced materials, biotechnologies and information technologies have been identified as forming the basis of the transition of Japanese industry to high technology into the next century.

Japan is well on its way towards attaining technological leadership in an increasing array of industries through its long run, coordinated, systematic and selective promotion of advanced materials synthesis, processing and commercial application. For example, USA leadership in microelectronics is under serious challenge from Japan, which has taken the lead in several semiconductor fabrication techniques. Similar tendencies are emerging in optoelectronic product development, fabrication and commercialisation.

As the USA's National Critical Technologies Panel points out, Japan has long laid strong emphasis on materials **process technologies**. This has been a determining factor in superior Japanese world class performance in several industries.

The findings reported in this study offer dramatic confirmation of the view that while western scientists concentrate on examining the properties of new materials, Japanese scientists and engineers concentrate on their synthesis and processing, together with a strong orientation towards commercial application. Hence, despite the relative superiority of the USA or Europe in a range of new materials R&D, it is more likely that Japan will ultimately lead in the commercialisation of several key new materials technologies, including superconductors, from the late 1990s onwards. This is likely to be strongly reinforced by the application of Kaisen (continuous improvement) techniques to high technology activities. Kaizen constitutes the central distinguishing feature between Japanese and Western companies.

Japan possesses strong and superior engineering skills both in materials processing and across the manufacturing base. The integration of new materials into simultaneous product and manufacturing process design, a practice already widespread, will almost certainly confer even more decisive advantages to world class manufacturers in industry after industry.

It is not widely recognised that hundreds of Japanese materials producing and using firms entered new materials from the early to mid-1980s onwards. Following an early, and disappointing experimentation with novel materials, the emphasis in the last four years has been on processing and commercial application for a narrow set of materials already developed and connected to core strengths. The recession of 1991-1993 has put a strain on new materials departments and has forced a re-evaluation of some of the more ambitious diversification strategies. Nevertheless, it must be stressed that new materials and their commercialisation retain their importance in corporate strategy and continue to be systematically pursued. It is more than likely that Japan will emerge[2] from the current recession leaner, fitter and stronger, ready for a next wave of expansion based on a command of several key technologies, including new materials.

Strong government-university-industry institutional linkages exist in pre-competitive and near-market R&D. Where the new materials technology is of a radical or novel nature, too risky and expensive for private firms, but considered crucial or possessing great potential for long term growth, it is promoted in large scale government projects conducted at government laboratories belonging to the Ministry of International Trade and Industry's (MITI) AIST and the AST, where private industry is also encouraged to participate. In addition, fiscal incentives and financial support are provided through the Japan Key Technology Centre to inter-firm consortia exploring pre-commercialisation.

Japan is currently engaged in a policy-driven rationalisation and restructuring in preparation for the next wave of expansion, predicated upon a mastery of several critical high technologies, including opto-electronics, advanced materials and biotechnologies, providing her with an unassailable position in many world markets. The research and evidence associated with this study provide strong evidence for the view that Japan is likely to acquire technological supremacy and a major competitive weapon in the world markets of the 1990s and early part of the 21st century through its ability to process and commercialise new materials technologies[81], despite the current difficulties[82]. Indeed the deepening recession is leading many companies to focus on new technologies with renewed vigour born out of necessity.

8. THE ROLE OF ADVANCED MATERIALS IN INDUSTRIAL RESTRUCTURING IN SOUTH EAST ASIA

8.1 Major efforts in building up domestic competence

The analysis highlights the rising importance of advanced materials in the process of industrial restructuring within and between Japan and South East Asian economies over the last decade. Industry is shifting to higher value-added activities and more technologically sophisticated products and industrial processes. However, many firms in the region have been hampered in their attempts to compete in the world market by the lack of critical raw materials, pure powders, components and parts. The simple formula of combining cheap labour with foreign technology acquisition and licensing (mainly from Japan), which formed the basis of the growth and export success of the 1970s and 1980s is now facing serious constraints. Access to critical materials and components and advanced technologies from Japan is either not forthcoming or too expensive. Quite rationally Japanese companies are unwilling to give away core technologies to potential competitors. Moreover, these economies badly neglected both engineering design and pure and applied R&D skills during the earlier labour intensive phase of industrialisation. These deficiencies are now posing a serious handicap in economies such as the Republic of Korea and Taiwan Province of China, squeezed between the high technology advantage of Japan and low-wage advantage of regional developing economies, such as China, Indonesia, Malaysia and Thailand.

Major efforts are under way in the NIEs of the region to build up domestic competencies in advanced materials, components and devices. Considerable emphasis has now been placed in both Taiwan Province of China and the Republic of Korea on the need to enhance domestic materials synthesis and processing skills in order to facilitate the transition to high technology in the 1990s. Policies to promote domestic and in-house materials competencies necessarily ascribe an important role to foreign professional societies, universities, research centres and companies in the forefront of scientific and technical advance. This opens up opportunities for cooperation and skills acquisition between developing economies.

Tremendous opportunities exist for western firms in steel, aluminium, chemicals pharmaceuticals, glass, ceramics, cement, electronics, machinery, cars and automobile components in terms of technology with firms in both first and second tier NIE economies in East Asia. Although Japan remains an important supplier of technology in the region, in some cases still the preferred one for cultural and historical reasons, there is a strong and evident desire to diversify sources of supply. European and American firms would be received very favourably in this, the highest growth region in the world in the 1990s. Major opportunities exists in chemical specialties and advanced polymers in both Taiwan Province of China and the Republic of Korea in the 1990s.

A very complex web of intra-firm and intra- and inter-industry division of labour is emerging. Firms in Japan retain highly-skilled critical component production and segments of the assembly process within Japan, while relocating other segments and sub-assemblies to first and second tier NIEs and other labour abundant, low wage economies such as Indonesia, and increasingly China and Viet Nam. Moreover, as labour skills, real wages and labour shortages are rising in the Republic of Korea, Taiwan Province of China, Singapore and even Malaysia, firms are withdrawing from their high wage locations and relocating plants and unskilled segments of the production process to the lower cost economies of the region. On the other hand higher wages and skills mean larger and more sophisticated markets and this is now reflected in the type of foreign direct investment encouraged and flowing into the Republic of Korea, Singapore and Taiwan Province of China.

The need for higher quality and high performance materials and components is increasingly felt in the region in response to changing demand and locational patterns in user industries, as in electronics and automobiles.

8.2 Strategies in the 1990s

The problems, difficulties and successes experienced and strategies adopted by Japan and her South East Asian neighbours provide a major source of learning and critical study by many other developing, industrialising and developed nations in the 1990s.

In early 1992 the Government of the Republic of Korea launched the Highly Advanced National Project (known as the G-7 Project). This aims to bring the nation's scientific and technological capabilities to the level of the industrialised G7 countries by the year 2000. The first part of the Project supports seven major near market technologies (next generation integrated semi-conductors, ISDN, high definition television (HDTV), the electric vehicle, intelligent computers, antibiotics and chemicals for agriculture and advanced manufacturing systems). The second part supports more fundamental or basic technologies, including advanced materials, next-generation transport systems and biotechnology. Final plans for the advanced materials projects were announced in August 1992. Most of the research will be undertaken by the Korean Institute for Science and Technology (KIST) and related institutes. The Korean Academy of Industrial Technology (KAITECH) will coordinate and fund near market research by government laboratories, industry and universities.

Taiwan Province of China aims to achieve the status of a fully industrialised economy by the year 2000. At the forefront of this lie nine high technology sectors, namely: communications, information, consumer electronics, precision machinery, automation, semiconductors, specialty chemicals and pharmaceutical, health care and pollution control. In order to support the shift to the nine high tech sectors, several key advanced materials technologies have been given priority and selected for development in a concerted effort in the 1990s. The Materials Research Laboratories (MRL) of the Industrial Technology Research Institute (ITRI) is the main institution responsible for advanced materials R&D programmes and technology transfer in Taiwan Province of China.

Singapore aims to become an advanced industrialised nation by the year 2030. The government is to allocate up to $2 billion to an R&D fund the aim of which is to develop skills, manpower and technologies specific to industry's needs. In addition, 200 foreign research scientists and engineers are to be recruited annually over a five-year period by the newly formed National Science and Technology Board (NSTB) whose function is to promote **industry driven R&D.** The government is encouraging large multinational corporations in electronics and chemicals to set up local R&D and design centres in the context of long run strategic objectives into the next century, which envisages Singapore as a major international centre for scientific and technological excellence.

The Government of Malaysia has recently set the goal of full industrialisation by the year 2020. This is known as the "Vision 2020". The aim is to restructure industry towards high value-added production while abandoning labour-intensive activities, such as textiles. There is a distinct emphasis on the promotion of high technology, capital intensive projects (given the emerging labour shortages). In electronics, which is spearheading manufacturing and export-led growth in the 1990s, the emphasis is on backward and forward integration. Malaysia aims to promote the production of a larger range of sophisticated electronics domestically and move to higher levels of technological sophistication in downstream activities using these components.

In Thailand, manufacturing industry has grown exceedingly fast over the last six years. This has put enormous strains on a weak, but very slowly improving infrastructure. Moreover, it has highlighted constraints imposed by a lack of a network of high-precision, high-quality component and parts suppliers and supporting industries and services. The development of supporting industries and domestic parts and component supplies ranging from engineering to electronics and automobiles is now an urgent government priority. Hence large opportunities exist for foreign firms to invest in an array of core supply industries in chemicals, metal working, automotive parts, electronics and machinery.

8.3 Restructuring in SE Asia and the shift to high technology by the year 2000

The path of export oriented industrialisation associated with the rise of the NIEs in SE Asia in the 1970s and 1980s is now beginning to face serious constraints. Recent developments have uncovered the fragility upon which the industrialisation process now rests. As labour skills and real wages have been increasing, industry is shifting towards high value-added sophisticated products and processes aimed at specific niches in the world market, and towards high-technology activities in micro-electronics and, less so, aerospace. This restructuring though is severely hampered by the non-availability of critical materials and components, as well as the lack of indigenous R&D and design capabilities, areas neglected during the earlier labour-intensive phases of industrialisation. Export success in previous periods tended to rest on the simple formula of foreign technology acquisition and licensing combined with cheap labour. The flow of new technology from Japan to the region has slowed down, including critical advanced materials and components entering products and processes in a range of sophisticated industries. Given the current level of development of Republic of Korean and Taiwanese skills and technology, Japanese firms are, understandably, reluctant to provide key advanced technologies and inputs to potential competitors. On the other hand, Japanese firms are aware of their responsibility to contribute to the economic development of the region and are making efforts in this direction. Moreover, they claim that firms in the region are not willing to pay the right price for the expensive technologies that Japan developed. The efforts of Taiwan Province of China and the Republic of Korea to shift towards high technology and become world class competitors, challenging Japanese high quality products, such as cars and consumer electronics in both Japan and foreign markets, are still thwarted by the strong dependence[85] on Japan for state-of-the-art technology and components. Some firms have successfully challenged Japanese pre-eminence in semiconductors (e.g. the Republic of Korea's Samsung) or specific market niches such as in notebook PC's (e.g. Taiwan Province of China's Twinhead International Corp.). But in many activities, firms in the two economies have no choice but to continue to rely on Japanese processing equipment (e.g. for printing circuits on DRAM chips) or electronic components for computers, TV sets and VCRs, for otherwise they would be forced to remain at the very low end of the market. In a number of areas domestic efforts to develop self-reliance in critical components have not yet paid off or are proving too difficult, or would take too long to develop thereby losing time-based competitive advantage. Hence Samsung's and Goldstar's decision to import cathode-ray tubes for large screen TVs bound for the US market from Toshiba and Hitachi. Japanese content for most of the Republic of Korea's high end TVs and VCRs is still around 15-20 per cent, with companies like the Republic of Korea's Lucky Goldstar or Taiwan Province of China's Sampo Corporation finding it very difficult to break lose from reliance on Japanese technology for such products. In 1991 alone, Japanese high-tech imports from Japan amounted to US$ 21.1 billion for about 93 per cent of the Republic of Korean's import bill.

Technology still flows from Japan to Taiwan Province of China and the Republic of Korea, with about 31.3 per cent of the latter's royalty payments going to Japanese licensors. But critical state-of-the-art technologies and components and know-how are not transferred or licensed (except where it serves a purpose, such as Hitachi's 1989 transfer of memory chip technology to Goldstar Electron for a fee and an agreement to invest US$ 2 billion for plants to make the chip). As a Japanese electronics representative in Seoul aptly put it, you do not fight with your competitors by sharing your best weapons with them. This is the crux of the argument. Japanese companies[86] have a very clear understanding of what constitutes a core competence or critical material, component or technology and, not surprisingly, they would never licence or transfer that to a potential competitor. The Republic of Korea is consequently asking Japan for a whole list of advanced technologies, including design for HDTV chips, chemicals, machinery, robots and camcorders. But there has been no breakthrough on this, nor is there likely to be.

Both the Republic of Korea and Taiwan Province of China are feeling the pressure from a Japanese competitive strategy that aims not only to deprive them of state-of-the-art technology but also to combine superior technology and low cost labour, by locating plants in low-wage economies in Thailand, Malaysia and Indonesia[87]. Given the relatively high wage costs in the Republic of Korea and Taiwan Province of China (with average wages of US$ 800 against US$ 120 per month in Malaysia) and high value currencies, this Japanese strategy is squeezing both economies out of Japanese, European and American markets, on both quality and price. Apart from efforts to extract greater access to Japanese technology and domestic markets, the Republic of Korea and Taiwan Province of China are responding by increasing efforts to upgrade domestic R&D and technological capabilities, with little success as yet, and reduce reliance on Japan. Many companies are turning to American and European firms for the supply of new technology and knowhow, in an attempt to reduce dependence on Japanese technology. And in an attempt to increase domestic self-reliance, reduce import dependence on the Japanese and cut the massive trade deficit with Japan, the Republic of Korea bans 258 Japanese products, and Taiwan Province of China bans Japanese cars. Vast opportunities therefore exist for western firms for the supply of technology (with the Republic of Korea's royalties to the USA exceeding those to Japan by US$ 173 million in 1990) and critical materials and components to both economies.

Consequently there is considerable emphasis is both the Republic of Korea and Taiwan Province of China on the strategic acquisition of in-house and national materials synthesis and processing skills. Advanced materials formed the bulk of the ten national projects identified in 1990 as urgent priorities for the Republic of Korean government support and promotion. Similar priorities are emerging in Taiwan Province of China. Given the size of Singapore's economy, the emphasis is on advanced materials applications, together with the provision of supporting and maintenance services for companies in aerospace and microelectronics. Nevertheless, the development and application of new materials by national and foreign firms relies on extreme environment, complex instrumentation, and characterisation technologies provided by very well equipped and manned national standards institutes, which are acquiring a pivotal role in the industrialisation strategies of these economies. Given the importance of international standards the activities of VAMAS are highlighted at the end of thisstudy.

It is becoming clear that the transition towards more sophisticated and high technology activities requires a critical mass of domestic materials synthesis and processing technologies. As these competencies grow at the level of the firm and the economy, the easier it becomes to attract, access and absorb technologies from abroad. Internal competence building and external mechanisms via inter-firm cross-border alliances thus go hand in hand. Here the degree of liberalisation of the domestic economy, protection of intellectual property rights and open door policy to foreign investment and technology flows are becoming critical for the successful outcome of these policies.

The restructuring of NIEs has opened up opportunities for the rise of resource-based and labour intensive activities in second tier NIEs such as Malaysia and Thailand, and in Indonesia, the Philippines and recently, Viet Nam and China. Many firms from Japan, the

Republic of Korea, Taiwan Province of China and Singapore are withdrawing from their high wage locations and relocating plants and unskilled segments of the production process to the low wage cost economies in the region. Hence a very complex intra-firm and intra, inter-industry division of labour is emerging, in which firms retain high skill, critical component production and assembly segments in Japan, while relocating other segments and sub-assemblies to first and second tier NIEs in the region. At the same time, the development of the productive forces, skills, wages and markets in the NIEs is encouraging foreign direct investment to meet the needs of the expanding and more demanding domestic market. Moreover, while Thailand and Malaysia are rapidly moving towards NIE's status through a remarkable expansion of their manufacturing base, especially in electronics, ambitious plans to become advanced industrialised economies have been unveiled by the Republic of Korea and Taiwan Province of China by the year 2000 and Singapore by the year 2030.

ANNEX

THE VERSAILLES PROJECT ON ADVANCED MATERIALS AND STANDARDS

At the 1982 Economic Summit held at Versailles the G7 Heads of State and the Representatives of the European Communities agreed to a Working Group on 'Technology, Growth and Employment'. One of the specific science and technology proposals springing from the recommendations related to Advanced Materials and Standards and the setting up of an international collaborative research effort under the name Versailles Project on Advanced Materials and Standards (VAMAS). Materials technology is viewed as an enabling technology, increasingly exercising a major influence on innovation and growth in a range of industries, including construction, electronics and mechanical engineering. Moreover, materials-related innovations provide industry with substantial opportunities to create new products for competitive advantage in the world market, as well as meet socio-economic needs in the areas of energy conservation, environmental protection, safety, health and transportation. Nevertheless, the development, application, acceptance and diffusion of new materials technologies depend critically on the availability of appropriate methods of materials specification and evaluation, and codes of practice. It is the recognition of this fact that led to the formation of VAMAS. The aim[88] is to provide international collaboration in pre-standards research, advanced measurements and databases, which would lead to the development of harmonised standards and codes of practice. Commonly acceptable standards and specifications would enhance confidence in industrial applications and would lead to a generalised diffusion of new materials, to the greater utilisation of improved existing materials, and promote world trade in high technology products incorporating advanced materials.

VAMAS is managed by a Steering Committee (SC). Pre-standards research under VAMAS is organised into Technical Working Areas (TWAs), which are approved by the SC and led by international chairmen. Fourteen TWAs have been established, and one has already completed its work. Over 350 research groups have participated in the programme, including some from eight non-summit countries. Industrial, academic and government laboratories have been involved, while industry has provided additional support by contributing materials for testing and round-robin exercises.

The fourteen Technical Working Areas (TWAs) identified below, embrace all important aspects of pre-standardisation research, including the development of the basis for a materials classification scheme, reliable and reproducible test methods, specifications for materials property determination, reference materials, and database formats. Nearly sixty projects cover organic, inorganic and metallic materials, as well as thin films, coating and composites. Materials behaviour relating to thermal, electrical, chemical, mechanical and physical properties is also under investigation.

Very few international standards on advanced materials currently exist; VAMAS has not yet achieved an international standard, but the national standards resulting from VAMAS would be derived from an internationally accepted and compatible body of knowledge. VAMAS is making in-roads in several directions, especially in the area of advanced ceramics.

VAMAS is in a unique position to foster international co-operation in pre-standards research, enhancing awareness and bringing together researchers from many countries, especially given that costs and information requirements are often beyond the means of a single state. Given progress already made and the critical importance of standards and specifications in national and regional markets (including the large number of standards required in the European Single Market after December 1992), a recent independent report[89] recommended that the agreement be extended for at least another five years to 1997.

VAMAS: TECHNICAL WORKING AREAS

AREAS AND OBJECTIVES	CONTACT
WEAR TEST METHODS: This TWA was established in 1984 with the objectives of "improving the reproducibility and comparability of wear tests by developing internationally agreed wear test methodologies, and of characterising the wear behaviour of advanced materials". Wear and corrosion are economically the most important processes of material deterioration. Wear has been defined by the OECD as the progressive loss of substance of a body occurring as a result of relative motion at the surface. The introduction of new and improved materials has been hindered by lack of reliable data and codes of practice because of the complexity of friction and wear processes and the lack of standardised wear test methods. Materials: Alumina, silicon nitride, AISI 52100 steel.	Dr. E. Santner, BAM, Unter den Eichen 87, D-100, Berlin 45, Germany. Tel: 010 49 30 8104 0020 Fax: 010 49 30 811 2029
SURFACE CHEMICAL ANALYSIS: This TWA has been operational since 1984. Its main objective is to "produce, by co-ordinated effort, the reference procedures, reference data and reference materials necessary to establish standards for surface chemical analysis". Such standards are needed because of the importance of surface analysis in modern technologies involving surface treatment or depositing films, e.g. microelectronics, ion implantation, coating and plasma processing. To date 30 projects have been developed, mainly pertaining to the use of Auger electron spectroscopy (AES), X-ray photoelectron spectroscopy (XPS), secondary ion mass spectroscopy (SIMS) and sputter depth profiling (SDP) for qualitative and quantitative analysis. Some projects involve materials and their data, while others involve the development of algorithms that must be validated. The work as whole is beyond the resources of any one Member State. This TWA has provided the VAMAS umbrella for co-ordinating international activities so that databases and software can be harmonised by working standards. It has enables more accurate and reliable surface analyses to be made, thereby stimulating the development of advanced materials in new technologies. Materials: Wide ranging reference materials, metallic and non-metallic.	Dr. M. P. Seah, Division of Materials Metrology, NPL, Teddington, United Kingdom, TW11 0LW Tel: 010 44 81 943 6634 Fax: 010 44 81 943 2989
CERAMICS: TWA3 was launched in 1984 with the objective of investigating the reliability and reproducibility of test procedures for advanced ceramics prior to formal standardisation. Engineering ceramics are exploited for properties such as high hardness and wear resistance and good dimensional stability, and offer the promise of outstanding high temperature performance. Their application in some areas such as engines has been disappointingly slow, in part because of the lack of assurance of the long term reliability of ceramics in structural applications. Standards are needed to enhance the supplier and user confidence in property levels and test procedures. Materials: Alumina, zirconia-alumina ceramics.	G. D. Quinn, NIST, Gaithersburg, MD 20899, United States of America Tel: 0101 301 975 5657 Fax: 0101 301 890 9729

POLYMER BLENDS: The objective of TWA4 is to provide the technical basis for drafting test procedures for new high performance alloys and blends. The latter are mixtures of polymers characterised by immiscible and distinct phases. All commercial blends are multi-phase and test methods for homogeneous polymers are not considered sufficient. At the first of its annual meetings in 1985, this TWA identified five areas of study, viz. melt flow, dynamic testing, thermal properties, morphology and mechanical properties for a Phase I programme on non-commercial polycarbonate/polyethylene blends. The resulting test procedures would then be applied to commercial blends in a Phase II programme. This TWA is strongly industry-orientated, the considerable volume of material being donated by commercial suppliers. Materials: Polycarbonate/polyethylene blend, orgalloy R-6000 commercial blend.

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POLYMER COMPOSITES: The work area was approved by the Steering Committee in 1985 because of the need to characterise and predict the mechanical behaviour of polymer composites under representative conditions. The objective of its first project was to assess and refine the measurement of fracture toughness for delamination crack growth. A round-robin test programme, led by France, involved 14 laboratories and four VAMAS nations, in co-operation with ASTM, and extended a previous ASTM programme to a wider range of glass and carbon fibre composites and to both thin and thick sections. Toughness criteria were determined in tension and in shear modes under monotonic loading. Materials: Glass and carbon fibre reinforced resins.

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Fax: 010 33 1 427 19329SU-

SUPERCONDUCTING AND CRYOGENIC STRUCTURAL MATERIALS: Superconductivity provides the basis for advanced technological programmes involving superconducting generators, large scale accelerators, nuclear magnetic resonance equipment for medical diagnosis, and associated cryogenic structures. In order to exploit the results from such programmes, standards for reliable property measurements on superconducting and cryogenic structural materials are needed. This gave rise to TWA6, which was approved by the Steering Committee in 1985 and held its first meeting in April 1986. Being aware of existing work on the testing of these materials in co-operative Japan/USA and EC programmes, it focused its early activities on round-robin tests for measuring cricital current in superconducting Nb_3Sn multifilamentary wires supplied by the USA, Japan and the EC. The objective of this and subsequent activities was the establishment of reliable measurement techniques that would lead to standards. Materials: Niobium-tin and niobium-titanium filaments, cryogenic steels.

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BIOENGINEERING MATERIALS: This TWA is based on the "recognition that the performance of replacement materials used in the human body cannot simply be predicted from the properties in normal environments". At its early meetings it identified the need to emphasise research on materials in contact with both hard and soft tissues. Materials: Hydroxyapatite, alumina, zirconia.

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HOT SALT CORROSION RESISTANCE: Hot salt corrosion problems arise in gas turbines operating in marine environments as a consequence of ingested salt combining with sulphur present in the fuel during combustion. In January 1985, the Steering Committee recommended the setting up of TWA8 to harmonise known test procedures and develop an internationally acceptable procedure for assessing the hot salt corrosion resistance of superalloys used in gas turbines. Earlier round-robin tests by ASTM in the USA and an intercomparison exercise under COST 50 in Europe had shown little consistency in the ranking of alloys when the results of various test methods were compared. Materials: Rene 80 and IN738 nickel-based superalloys, protective coatings.

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WELD CHARACTERISTICS: Future research will be undertaken by the International Institute of Welding. Materials: 304 and 316 austenitic steels.

Completed.

MATERIALS DATABANKS: Materials databanks are becoming important elements of the computerised flow of information on materials properties. Standards are needed for models that relate o the flow of information from its generation to its use. The methods for materials data interchange, using formats agreed at an international workshop in 1989, will be compared in exchange tests between institutions. An inter-laboratory comparison of data evaluation models (17 for creep data and 12 for fatigue data on steels) organised by NRIM Japan has been completed with the involvement of 15 participants from 5 VAMAS nations and reported in VAMAS TR6 and TR7. This will be followed by assembling an inventory of method/models for materials data analysis. A United Kingdom-led task of compiling an inventory of materials designation systems is underway. Materials: Creep and fatigue data from low and high alloy steels.

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CREEP CRACK GROWTH: The overall aim of TWA11 is to develop a unified approach to the measurement and interpretation of data on the growth of creep cracks, i.e. cracks that grow with time under steady load conditions in components operating at high temperatures in power engineering and chemical plant applications. It is important to have reliable data on crack growth rate because of its influence on inspection intervals and on residual life prediction. Materials: Cheomium/molybdenum/vanadium ferritic steels.

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EFFICIENT TEST PROCEDURES FOR POLYMER PROPERTIES: This TWA arose in 1986 because of the desire to validate short time tests series that would reduce the need for extensive property evaluations on polymers, i.e. time-dependent viscoelastic materials. A broad survey of current procedures and of national preferences among VAMAS participants was made to determine their priorities with respect to different aspects of testing such as creep, fatigue, stress relaxation, durability, dynamic stiffness etc. The outcome of the meeting in May 1988 was to focus on the durability of polymers in aggressive environments such as heat, light and water, with particular reference to accelerated tests, the broad objective being to support standardisation activities in this field. Materials: Polymers (to be specified).

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LOW CYCLE FATIGUE: Low cycle fatigue (LCF) tests are essential to ensure the safe operation of parts that are sometimes repetitively stressed into the plastic region. The objective of this TWA, approved in 1986, is to identify those aspects of testing procedure that significantly affect the repeatability and reproducibility of the results of LCF tests at high temperatures. Such aspects include test variables that are not standardised eg specimen size and shape, extensometer type and failure criteria. Materials: IN718 and Nimonic 101 nickel base alloys, 316L and 9Cr/1Mo steel.

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THE TECHNICAL BASIS FOR A UNIFIED CLASSIFICATION SYSTEM FOR ADVANCED CERAMICS: TWA14 is the most recent TWA to be approved (September 1988). Because only limited classification of ceramics exists, it was proposed that a world-wide classification for advanced ceramics should be developed instead of bringing national systems together. The prime objectives are (1) identification and assessment of the issues inherent in developing a classification system for advanced ceramics, (2) establishment of a building block structure for international use, and (3) development of mechanisms and institutional links for system implementation. Materials: Engineering ceramics.

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REFERENCES

1. The current recession and the potential for a slide into greater protectionism and generalised depression by the major economies ought not to deflect attention from the importance of the scientific and technological trends identified herein for long run innovation, competitiveness and growth. No Japanese company would discard R&D on fundamental core technologies deemed essential for long run growth, even in the face of adverse market and profitability conditions in the short to medium run. The tariff reductions agreed at the Tokyo G7 Summit in July 1993 and the resolution of the Uruguay Round of the GATT talks in December 1993, opened up the possibility of higher rates of growth and trade expansion in the coming years.

2. Especially given the massive Yen 40 billion domestic fiscal injection announced by the government in August 1992 and April 1993. However, the results of these fiscal boosts remain unclear at present. In February 1994, the Japanese Government announced a record US$ 95 billion boost to the Japanese economy, raising hopes of a recovery by early 1995.

3. The issues identified in this series are examined in greater depth in two further studies by the author. See Lakis C. Kaounides (ed.) 1994, **Advanced Materials Technologies – Strategies for Industrial Competitiveness and Growth into the 21st Century**, Institute of Materials, London (UK), and United Nations Industrial Development Organization (UNIDO), Vienna, Austria, IM Publications, London (UK); and Lakis C. Kaounides, 1994, **Advanced Materials – Corporate Strategies for Competitive Advantage in the 1990s,** Management Report, The Financial Times Publications, London (UK) (May 1994).

4. The term is first used in the MIT's five-year path breaking study, *The Machine that Changed the World*, Womack et. al. (1990), Rawson Associates 1990. Lean production methods include just-in-time, company-wide quality control, zero defects, continuous improvement activities (Kaizen), total preventive maintenance, working multiskilling, teamwork, simultaneous engineering in product development and new methods of managing the supply chain and customers.

   The basis of the new production methods are to be found in the Toyota production management system painstakingly developed by Toyoda and Ohno from 1947 to the early 1970s, both of whom rejected Fordist mass production as inefficient and wasteful of raw materials, inventories and labour, including skills and initiatives of the latter.

   For a recent wide ranging critique of both lean production and the claims made in the MIT study referred to above, see *"Lean Production and Beyond: Labour Aspects of a New Production Concept"*, International Institute for Labour Studies. ILO: Geneva, 1993.

5. See Brainard, R., "Internationalising R&D", The OECD Observer, February/March, 1992, and OECD,"Technology and Globalisation", Ch. 10 in *Technology and the Economy*, Paris: OECD, 1992.

6. Katz, M. L., and Ordover, J., "R&D Cooperation and Competition", Brookings Papers on Economic Activity: Microeconomics, 1990. The dangers of deskilling and hollowing out arising from joint R&D ventures are highlighted by Lei, D. and Slocum, J.W., "Global Strategy, Competence-Building and Strategic Alliances", **California Management Review**, Fall 1992.

7. Mowery, D., and Rosenberg, N., *Technology and the Pursuit of Growth*, Cambridge University Press, (1989).

8. See Professor Laura D'Andrea Tyson, "Who's Bashing Whom – Trade Conflict in High Technology Industries", Institute of International Economics, Washington, 1993. Dang N'Gyyen, G. and Owen, R.F. (1992), "High-Tech Competition and Industrial Restructuring in Light of the Single Market", AER Papers and Proceedings, May 1992. **The Economist**, Europe's Technology Policy, 9 January

1993.

9. We examine science, technology and industrialisation in the Far East, in L. Kaounides (ed.), *Advanced Materials Technologies – Strategies for Industrial Competitiveness and Growth into the 21st Century*, Institute of Materials Publications, Institutes of Materials and UNIDO: London, March 1994. This in essence is a companion volume to the present one. Corporate strategies are examined in Kaounides, L., "Advanced Materials – Corporate Strategies for Competitive Success in the 1990s", Financial Times Management Report, **Financial Times**, London, May 1994.

10. In doing so we must move ahead of the tired debate as to whether the "government can pick winners". The question is normally posed by those with a strong belief in market processes and an aversion to any form of government intervention. The answer is invariably "no", qualified, at best, with some reference to Japan as providing an exception, which nevertheless cannot or ought not to be emulated. Not only is the question wrongly posed, but even in its own terms it should be pointed out that "industrial policy" can be market led and industry informed rathern than government led and imposed, as is sometimes implied. Private industry in Japan plays the leading role in the selection and development of critical or commercially promising high-technology areas. Moreover, we must ask if something fundamentally new is occurring today, and if so what the implications are for government's role and for industrial policy. See Thurow, L., *Head of Head – The Coming Economic Battle Between Japan, Europe and America*, Nicholas Brealy Publishing, 1993, on western misconceptions over Japanese industrial strategy. Further comments on this are to be found below.

11. The scientific push and market pull factors leading to the development and application of new materials is discussed by Sir John Collyear, in his Presidential Address, "Materials for Society", Institute of Materials, London, 13 May 1992. He foresees a continuing importance for steel, but also points to the challenge posed by carbon fibre composites and aluminium alloys in automobile bodies. The aluminium space-frame car leads to increased lightness, reduced tool costs, shorter design-to-production times and improved scrap value. Titanium may also challenge stainless steel in some applications. He foresees advancing applications for fibre reinforced polymers, for alloys and composites of aluminium, titanium or magnesium, engineering polymers, ceramic composites and intelligent materials.

12. See *Innovations in Steel: Cars for the 21st Century*, International Iron and Steel Institute, Brussels, 1991. The new customised car body steels and coatings include: formable/iron-zinc alloy coated; formable/hot dip single sided electrozinc; deep drawing/two sided electro zinc; deep drawing/zinc-nickle electrocoated; deep drawing/organic and zinc-nickel coated; high strength low alloy; pre-painted drawing quality; dual phase high strength; high strength rephosphorised.

13. US National Research Council, Materials Science and Engineering in the 1990s: *Maintaining Competitiveness in the Age of Materials*, 1989, US Materials Research Society, A National Agenda in Materials Science and Engineering: Implementing the MSE Report, February 1991. Lakis C. Kaounides, International Business Strategies in Advanced Materials Technologies, **IDS Bulletin**, University of Sussex, Vol. 22, No. 1, April 1991. Lakis C. Kaounides, Advanced Materials in a Long-Wave Perspective, Paper presented at Science Policy Research Unit, Seminar Series, University of Sussex, 29 November 1991.

14. A lively debate is taking place in the USA over the need to develop an "industrial policy" and support pure and applied scientific research, thus providing firmer foundations for technical advance, in the light of the Japanese challenge and experience over the last two decades. See "Industrial Policy", Cover Story, **Business Week**, 6 April 1992, and **Nature**, Vol. 355, 6 February 1992. We are not arguing here for a simplistic unidirectional flow. The interaction is in practice far more complex and two-way. For example, basic scientific research may be undertaken or sparked off by practical technological difficulties, insights or commercialisation prospects in industry. See R.R. Nelson and N. Rosenberg, Technical Innovation and National Systems, in Nelson, R., (ed.) (1993), *National Innovation Systems*, Oxford University Press.

15. At a science policy colloquium held by the American Association for the Advancement of Science in

May 1992. The possession by the USA of a network of top research universities and a huge investment in fundamental research is seen as its greatest asset in the new scientific era, in which basic scientific research forms a close liaison with industry and commercial application.

16. A National Agenda in Materials Science and Engineering: Implementing the MS&E Report, 1991. The report summarises the results of four meetings across the USA involving over 400 participants from industry, academia and government.

17. It should be noted though, that a major advantage in Japanese pure and applied research is the ability to design and produce some of the world's best advanced instrumentation. Thus Japanese scientists and engineers have unparalleled advantages in the use of such tools to conduct excellent research in such fields as new materials, genetics and X-ray astronomy. Moreover, in the choice of scientific research that should be treated as a national project, government scientific institutions pay much attention to industry based scientists and engineers. **Nature**, Vol. 355, 16 January 1992.

18. **Fortune**, 18 May 1992.

19. In October 1991, Gaishi Kiraiwa, the Chairman of the powerful Kaidanren sent an exceedingly frank letter to Jiro Kondo, president of the Science Council of Japan, in which he pointed to profound concern over the government research system and the deterioration of the research and education environment of Japan's universities and laboratories, pointing out that the aim of building a country based on science and technology is "collapsing at the foundations". He called for a doubling of government spending on research of 1 per cent of GNP over the next five years. **Nature**., Vol. 354, 5 December 1991. A report from a Committee by Kazuo Inamori, president of Kyocera Corporation, of the very influential Council for Promotion of Administrative Reform, an advisory body to the Prime Minister, also supports the idea of doubling government spending on research to 1 per cent of GDP. The committee was responsible for looking into issues associated with the global environment, the growing political importance of science and the internationalisation of scientific research. Another report from a committee of Japan's top science policy-making agency, the Council of Science and Technology, was also expected to focus on the problems facing government funded basic research, in its recommendations for the next five to ten years. The LDP committee was expected to combine forces with MITI, STA and Monbusho in the summer of 1992 in order to influence the 1993 budget requests. It is not clear, at the time of writing, what the implications of the political crisis shaking Japan in the summer of 1993 will be for science policy. The election result of 20 July 1993 left Japan politically leaderless and a coalition government was formed in August 1993, which is currently preoccupied with political reform and the deepening economic and financial crisis.

20. The Human Frontier Science Programme supports basic research in molecular biology and neuroscience. It is a MITI initiative supported by the G7 and the EC, even though there is concern that Japan is attempting to pick western brains in this science area. The Frontier Science Programme and the Intelligent Manufacturing System (IMS) programme are attempts by Japan to contribute money into fundamental research areas in order to counter criticisms that its industrial success was achieved at the expense of European and USA scientific research effort. The IMS programme, therefore, was again initiated by MITI three years ago, aimed at applying leading-edge information technologies to manufacturing, an area where Japan is already an acknowledged leader. It is potentially a milestone in research collaboration between Japan, the USA and the EC, but in the February 1992 meeting in Toronto the initial proposals (an international fund, central administration and a single research centre) were watered down into a two-year pilot-study, with three collaborative research projects taking place in the laboratories of the home countries, and financed by each of the participating countries (now the USA, the EC, Japan, Australia, Canada and European Free Trade Association). See **Nature**, 27 February 1992. For details of MITI and AST projects see Chapter 6.

21. The Government Role in Civilian Technology: Building a New Alliance, National Academy Press, 2101 Constitution Avenue, Washington DC 20418, USA.

22. Report of the National Critical Technologies Panel, Washington, January 1991. In March 1990 the US

Department of Defense published its first Critical Technologies Plan, focusing on technologies that will maintain the superiority of USA weapon systems.The technologies selected are related to those selected by the Panel above, and many are in fact "dual use" technologies with commercial implications. The US Department of Commerce in the Spring of 1990 also selected 12 key technologies in its Emerging Technologies: A Survey of Technical and Economic Opportunities, which compares the relative positions of the USA, Japan and the European Community.

23. "Technology for America's Economic Growth: A new direction to build economic strength". President W.J. Clinton, Vice President A. Gore, Jr., 22 February 1993. For a more detailed exposition of the USA's technology policy, see L. Kaounides (ed.) *Advanced Materials Technologies* (forthcoming 1994), Ch. 1, op. cit.

24. **Eurodiagnostic**, June 1993

25. See Ken Easterling, *Advanced Materials for Sports Equipment*, Chapman and Hall, 1993.

26 Synthesis and processing of new materials has, of course, been highlighted in many studies recently as the crucial element to bolster competitiveness. However, the book goes a step further and integrates new materials into the process of continuous improvement and concurrent engineering underpinning world class manufacturing standards. The US National Research Council, 1989, op. cit., US Materials Research Society, 1991, op. cit.

27 Lewis M. Branscomb, "Does America Need a Technology Policy", **Harvard Business Review**, March-April 1992. Critical technologies lists, such as the ones discussed above, put forward by proponents of a more active technology policy, exemplify for him everything that is wrong with the current state of the debate in the USA. But as we have pointed out, the Panel on Critical Technologies actually places heavy emphasis on commercialisation and lists most of the demand side measures put forward by Branscomb. The paper generated much response, captured in "Technology Policy: Is America on the Right Track?", Debate, **Harvard Business Review**, May-June 1992.

28. Identified through consensus, debate and close collaboration between government and industry, playing close attention to the views of scientists and engineers in both.

29. A growing trend by Japanese companies is the conduct of fundamental research outside Japan. The Cavendish Laboratories in Cambridge, UK, have collaborative agreements with both Hitachi and Toshiba to conduct research into quantum electronics. Both these companies have established R&D centres in Cambridge's Science Park, UK, while Sharp established its European research centre at Oxford's Science Park in March 1992.

30 See H.G. Jones, "Principles of Resource Allocation", Ch. 24 in Morris, D. (ed.), (1985), *The Economic System of the UK*, Oxford University Press. In equilibrium a perfectly competitive economy guided by the price system would achieve pareto-efficiency in the allocation of resources. Even if we accept the Pareto criterion in judging outcomes, in the real world markets and prices often fail to achieve allocative efficiency. This is due to the existence of monopoly and other "imperfect" market structures, externalities which lead to divergences between private and social costs and benefits, the presince of "public" goods, the lack of future markets for many commodities, the presence of excessive risk which may lead to the price system producing a bias against risky activities, and imperfections in the dissemination and acquisition of knowledge. For an overview of the instruments and performance of industrial policy in Europe see D.J. Morris and D.K. Stout, "Industrial Policy", Chapter 28, in Morris, D., (ed.), 1985, ibid.

31. See Daniel, I. Okimoto, Between MITI and the Market, Stanford University Press: Stanford, California (1989). Industrial policy using tools such as fiscal incentives, R&D subsidies, trade protection and so on is employed in order to achieve certain national objectives. In Japan, MITI is concerned with enhancing productivity of factor inputs, improving the competitiveness of Japanese industry, move increasingly to higher levels of value added (while maintaining an infrastructure in basic industries, an efficient use of finite resources, good trading relations and an improved quality of life.

32. However, technological breakthroughs may rejuvenate declining sectors.

33. If the sector is shrinking "too slowly" when left to market forces, then government may intervene to accelerate the process, as in the structural adjustment of Japan's basic industries after the 1973 and 1979 oil crises. On the other hand many western governments have attempted to protect and arrest the rate of decline in shrinking industries.

34. See P.R. Kugman and M. Obstfeld, (1991), *International Economics*, Harper Collins.

35. As Krugman and Obstfeld (1991), op. cit., point out there are serious difficulties in implementing the theoretically valid technological spillover argument for industrial and trade policy. Which activities in a firm generate knowledge? Which firms in which industries generate knowledge and by what definition? Should government subsidise R&D activities across the board? Even if high-tech activities generate large technological spillovers and are consequently to be targeted, does the USA want to subsidise the generation of knowledge that could be appropriated by other nations?

36 Professor Laura D'Andrea Tyson (1992), *Who's Bashing Whom: Trade Conflict in High Technology Industries*, Institute for International Economics, Washington. Examples of spillover effects include reverse engineering of a private innovation, even with patent protection the benefits from a scientific and technological breakthrough that could extend beyond the individual innovating firm and the brain drain of personnel to new or competing firms. We will return to this below in the context of advanced materials.

37. P. Krugman (1986), ed., *Stratetic Trade Policy and the New International Economics*, The MIT Press.

38. However, Professor Tyson (op. cit., p. 39) argues that emperical evidence does not support the hypothesis that high technology industries generate excess profits or higher rates of return to capital than available in the rest of the economy. This finding is very relevant to strategic trade policy, referred to above, where proponents examine policy measures the aim of which is to shift the benefits of the alleged existence of monopoly rents between counries. On the other hand, internal cash flow in high-technology is an important determinant of R&D expenditures, especially in the presence of large risk and associated failure of capital markets to channel funds in that direction. Tyson's case studies indicate that the existence of trade barriers and structural impediments to trade have a direct bearing on the conduct of R&D and potential externalities via their negative impact on corporate sales and earnings. See also: Lawrence F. Katz and Summers, Lawrence H., (1989), "Industry Rents: Evidence and Implications", Brookings Papers on Economic Activity: Microeconomics.

39. This seems to be the direction of the argument coming from within the OECD. See *Technology and the Economy", 1992.*

40. A recent analysis of USA-Japanese alliances in semiconductors argues that the direction of technology transfer has been from the USA to Japan, endangering the technology base and competitiveness of the USA semiconductor industry over time. See US National Research Council, US-Japan Strategic Alliances in the Semiconductor Industry, National Academy Press, 1992.

41. The existence of logical agglomerations of firms in German and Italian industries enjoying dynamic external economics has been the subject of much debate within the "flexible specialisation" literature following the publication of M.J. Piore and Sabel, C.F., *The Second Industrial Divide*, New York: Basic Books, 1984.

These ideas have been heralded as opening up opportunities for new modes of manufacturing production and specialisation in certain developing economies, the first example of which was the important Cyprus Industrial Strategy conducted by a multidisciplinary team at the Institute of Development Studies, University of Sussex, UK, for the Cyprus Government/UNIDO/UNDP in 1986-87, and successfully implemented in recent years.

"Local" external economics and their impact on industrial growth dynamics go back to Alfred Marshall and the much neglected, but very important work of Allyn Young (1928), brought back to economists' attention by N. Kaldor in 1972 in his attach on the irrelevance of what he termed "equilibrium economics".

42. See Prof. McLaren in Lakis C. Kaounides (ed.), 1994, Advanced Materials Technologies, IM/UNIDO, op. cit., where he discusses the role of Rutgers University in advanced ceramics research in the USA.

43. M. Borrus, Laura d'Andrea Tyson, and John Zysman, Creating Advantage: How Government Policies Shape International Trade in the Semiconductor Industry", in P.R. Krugman (ed.), 1986, op. cit. See also M. Borrus, James Millstein and John Zysman, US-Japanese Competition in the Semiconductor Industry (Berkeley: Institute of International Studies, University of California, 1982), and Tyson, 1992, op. cit.

44. See the critical discussion of these issues in J.A. Brander, "Rationales for Strategic Trade and Industrial Policy", G.M. Grossman, "Strategic Export Promotion – A Critique", B.J. Spencer, "What should Trade Policy Target?", and A.K. Dixit, "Trade Policy: An Agenda for Research", in P.R. Krugman (ed.), 1986, op. cit.

45. Professor Laura D'Andrea Tyson, *Who's Bashing Whom: Trade Conflict in High Technology Industries*, Institute for International Economics, 1992.

46. It is doubtful that the acquisition of technological know-how through the purchase of products on the international market could effectively and with timeliness perform the function of keeping a firm on the technology frontier. On the other hand, cross-border technology and R&D alliances could make a positive contribution and may in fact be necessary for frontier R&D in high technology, as we point out elsewhere. Moreover, the presence of cumulative "learning by doing" skills and know-how is crucial in enabling domestic firms and R&D institutions to absorb, understand and utilise information and technologies generated elsewhere, through alliances or otherwise. Research alliances must not be seen as a substitute for in-house or domestic R&D capabilities.

47. See Lakis C. Kaounides, "Advanced Materials in a Long Wave Perspective: New materials and information technologies in a schema of expanded reproduction", paper presented at SPRU seminar series, University of Sussex, 29 November 1991, and "The Global Restructuring of Basic Industries 1970s-1990", paper presented at IV EADI Conference, Oslo, Norway, June 1990.

See Chart 1, which concentrates on one of the two main branches of industrial production. It illustrates the physical-technical relations of mineral-based material flows into an industrial system producing and using machinery and equipment.

48. See C.A. Sorrell, "Advanced Materials", *Minerals Yearbook*, 1989, US Bureau of Mines.

49. See Professor Colin Humphreys, Head of Materials Science, Cambridge University, UK, in "Can There Be a Materials Policy in the UK?", 1992.

50. The discussion below is much indebted to Okimoto, 1989, op. cit. He reminds us that many extremely important high technology industries in the USA were at first nurtured and grew up within the areas of the defense-oriented R&D system, with government playing a crucial supporting role as R&D contractor and customer. Infant industries thereby reached maturity and subsequently acquired their independence as domestic USA commercial demand began to grow. The USA defense-related R&D system and strong government support successfully created and then fostered the growing up of several new infant industries such as semiconductors, computers, supercomputers, telecommunications and others.

51. The degree of intervention and the selection of policy instruments has varied from industry to industry, but common to all has been heavy intervention in the early stages of an industry's life cycle and then again at the later saturation phase, while falling off to a large extent as the industry matures and grows in the intermediate phase. High technology activities at an early stage of their trajectory elicit a higher degree of government intervention followed by a certain amount of disengagement as they begin to mature. In semiconductors, the government still provides support at the sophisticated end due to the

importance of basic pre-competitive research of a "public good" nature. In the 1980s, MITI allowed much greater freedom to semiconductors as compared to the early 1970s. This is consistent with the view that government intervention serves little purpose once an industry acquires a strong and mature presence, together with the view that a different, more flexible approach is required for high technology industries operating at the frontiers of knowledge from the 1980s onwards. Industries, such as integrated circuits, automobiles, industrial machinery and consumer electronics, have now reached maturity, while aerospace, biotechnology, computer software and data processing, amongst others, are at an early stage of the industrial life cycle.

52. High technology firms operate in a fiercely competitive environment where the emerging scientific and technological know-how leads to fast product and manufacturing process innovation. Breakthroughs in technologies and products occur relatively frequently leading to a change in the competitive environment and influencing the direction, structure and organisation of the industry. Firms operating in this environment require heavy R&D and investment outlays simply to remain at the forefront of changes and meet the competitive challenge. At the same time the heavy R&D cost is accompanied by a high degree of uncertainty and risk, a shortening of product life cycles, and hence a shortening of the period for amortising expenditures and capturing rents. Moreover, differences in domestic structures of the industry, in terms of degree of vertical integration, concentration, specialised supplier firms and equipment makers, and so on, play an important role in the process of innovation at different stages of the industrial life cycle, and the ability to move from catching up to frontier product and process innovation, an issue still clearly at play in the USA and Japanese semiconductor industry.

53. It should be clear that the role of the government in high-technology is somewhat greater than even the considerations here entail. It involves the provision of infrastructure technologies not least in materials science and engineering, underpinning pure and applied R&D, commercialisation, new manufacturing processes and concepts and market developments. (See 4.9.)

54. For example, it was pointed out by Nippon Steel that an important reason for creating a new materials department in the late 1980s was in order to attract some of the best qualified graduates of Japanese universities. This is in sharp contrast to the employment preferences of the "best and brightest" in the USA or UK universities. In our view, one of the major reasons for the marked decline of interest in science and engineering subjects in A-level and higher-education studies by UK students can be traced to the lack of a clear vision of where industry is heading and what role science-based high-technology sectors will play in the UK's economy of the next century. Interest in science and technology is therefore low, and those who are attracted (or induced by recent cash-incentives by the government) tend to be neither the best nor the brightest.

55. See G. Tassey, (1992), *Technology Infrastructure and Competitive Position*, Kluwer Academic Publishers. Lester Thurow, 1993, op. cit., points out that Japan has identified the following key technologies: microelectronics, new materials science, biotechnology, telecommunications, civilian aircraft manufacturing, robots and machine tools, computers and software.

56. In information technologies, national R&D projects began in the early 1970s with the 3.75 series Computer Development Project, followed by several others including the (VLSI) and Fifth Generation Computer Projects more recently. Given impending liberalisation of the economy, the government felt that Japanese information technology had to leapfrog ahead through a crash programme of national projects. It must be noted though that the Japanese information industry had already reached a level of accumulated skills enabling it to more rapidly ahead, possibly without the assistance of a national project. Had the level of development been inadequate, then the national projects may have been ineffective in catapulting the industry to its world class competitive status through the 1980s. See Okimoto, 1989, op. cit., p. 68. This is an important point that applies equally to a range of other technologies. Technological leapfrogging ahead through cooperative R&D projects presupposes a domestic critical mass of accumulated know-how and skills in the relevant scientific disciplines and applied technologies.

57. This is apart from the benefits to MITI through its visible public demonstration of its commitment to

provide a competitive edge to Japanese industry and promote national welfare, the enhancement of its power base in the struggle between ministries and ability to extract more funds from the Ministry of Finance.

58. The difficulties of organising national R&D projects are considerable and are discussed by Okimoto, 1989, Ch. 2, op. cit.

59. Interestingly, Okimoto ascribes as much importance to the secondary effects of R&D projects, namely greater technological diffusion, company R&D commitment and intensification of competitive pressures, as to the primary objective of advances in state-of-the-art technologies and fundamental breakthroughs. If the latter cannot always be demonstrated, this should not be construed as failure for the project, since secondary effects may be considerable.

    A central issue is of course whether the costs outweigh the benefits and whether Japanese industry, if left to itself, would not eventually develop these same technologies, and moreover, faster than competitors. However, the secondary and cumulative effects of such projects could in themselves outweigh costs. Moreover, given the complexity, multidisciplinary nature, costs and risks associated with frontier technological development and commercialization in the 1990s, it is likely that joint R&D projects will increasingly play a central role in achieving both the primary and secondary objectives within national economies.

60. G. Tassey (1992), *Technology Infrastructure and Competitive Position*, Kluwer Academic Publishers.

61. As we point out throughout this study, standard testing and measurement methods have acquired a pivotal role in industrial competitiveness with the advent of advanced materials. See the activities of VAMAS at the end of this chapter.

62. A USA leadership in microelectronics is now under very serious challenge from Japan. Although the USA still has an edge in ion implantation, thin film epitaxy, thin film deposition and etching, falling behind in lithography, materials purity and ceramic packaging, Japan has taken the lead in several new semiconductors fabrication techniques, such as microwave plasma processing, radiation sources for lithography, electron and ion microbeams, laser assisted processing compound semiconductors processing, and 3-D device structures. Japanese companies are now dominant in memory devices, the largest segment of the IC market. While in 1980 the USA accounted for 53 per cent of global semiconductor sales, 75 per cent of semiconductors equipment sales and 70 per cent of computer system sales, Japanese companies pushed back these shares to 44 per cent, 47 per cent and 60 per cent respectively today. What is more, USA computer makers are increasingly dependent on components and hardware supplied by vertically integrated Japanese competitors. By 1995 Japan could possibly supply over half the hardware that enters into the world's computer industry. One consequence of this may be collusive behaviour by Japanese suppliers extracting monopoly prices from their customers, i.e. in semiconductors. Another may be that Japanese companies will not supply, or delay the supply of, state-of-the-art components and technologies to their competitors in order to maintain their lead, as, for example, in semiconductor fabrication equipment, according to a 1991 General Accounting Office study.

    Japan is also acquiring a leading role in product development, fabrication and commercialisation of optoelectronics. Japan already leads in semiconductor-based optoelectronic devices, such as laser and light-emitting diodes, photodiodes, charge-coupled devices, solar cells and optical fibre, by effectively integrating R&D and manufacturing. In moving towards new applications of optoelectronic devices in telecommunications and data processing, more advanced optoelectronic technologies are required, including optoelectronic integrated circuits. In both the USA and Europe, firms and research institutes are active in leading edge optoelectronics technology, but less so in their commercial application. On the other hand, Japanese firms and the government are systematically coordinating research under the optoelectronics projects of MITI, and encouraging western firms and research institutes to participate in the Sixth Generation Computer Project, which, in the main, aims to develop optical computing technology.

In both micro- and opto-electronics, Japan is making a concerted effort at pre-eminence in product, process and commercial applications and hence domination of a series of critical technologies dependent on those in the next century. See US Panel on National Critical Technologies, 1991, op. cit.

63. See also **Business Week**, "Reinventing America", Special Bonus Issue 1992, January 1993.

64. For example the USA leads in advanced composite research, production and use, with a strong position in high-performance applications, especially in aerospace and military aviation due to extensive Defense and NASA R&D sponsorship in PMCs, with little attention to lower end composites and commercialisation. In contrast, Japanese firms have acquired strong skills in composite design and manufacture in commercial applications, such as sporting goods, civil engineering, construction and other fields. They are therefore well positioned to take advantage of future growth of non-aerospace markets. What is more, through Toray Industries, Japan is the dominant supplier of carbon fibre. Another important development is the rise of European firms in PMC development and manufacturing through the acquisition of over 20 USA-based PMC suppliers in recent years, including some of the leading names. See US National Critical Technologies Panel, 1991, op. cit., and Ch. 6.

65. See M. Imai, *KAIZEN*, McGraw-Hill, 1986, The Kaizen Institute.

66. Private communciations. See also the **Nikkei Weekly**, September 1993.

67. For the role of MITI in supporting high-technology see the excellent study by Daniel I. Okimoto, *Between MITI and the Market: Japanese Industrial Policy for High Technology*, Stanford University Press: Stanford, California, 1989. Patrick, H., *Japan's High Technology Industries*, University of Washington Press, 1986.

68. Lakis C. Kaounides, "The Restructuring of Industry 1970s-1990s: From metals based to materials economies", paper presented at IV EADI Conference, June 1990, Oslo, Norway.

69. Indicative of these developments is the recent transformation of the American Society of Metals into the American Society of Materials, while in 1993 the Institute of Metals in London became the Institute of Materials.

70. **Business Week**, "The Death of Mining", Special Report, 1984

71. US Bureau of Mines, Commodity Profiles 1991, US National Research Council, Competitiveness of the US Minerals and Metals Industry, Washington, 1990.

72. *New Advanced Materials*, P. Cohendet, M.J. Ledoux, E. Zuscovitch (eds.), A Report from the FAST Programme of the European Communities, Springer-Verlag, 1988.

73. C. Oman, *New Forms of Investment in Developing Countries*, OECD, Paris, 1989.

74. See also L. Kaounides, "International Business Trends in Advanced Materials Technologies" in **IDS Bulletin**, April 1991, University of Sussex.

75. See L. Kaounides, "Advanced Materials in World Class Manufacturing: the next source of competitive advantage in the automotive industries", paper presented at 26th International Symposium on Automotive Technology and Automation (ISATA), Dedicated Conference on Lean Manufacturing in the Automotive Industries, Aachen, Germany, 13-17 September 1993. Published in the Proceedings, September 1993.

76. George Stalk Jr. and Thomas M. Hout, *Competing Against Time: How Time-Based Competition is ReshapinggGlobal Markets*, The Free Press, 1990.

76. Empirical evidence of the success of the technology-driven growth strategy restructuring towards high technology is provided in the recent issue of Japan's Economic Planning Agency, Economic Survey of Japan, 1990-91, August 1991.

77. The financial, economic and political crisis facing Japan in 1993 appears to be the worst in two decades,

with manufacturing industry therefore embarking on long-term restructuring plans to cut costs, increase efficiency and enhance competitiveness. **Financial Times Survey**, "Japan", 30 July 1993. Concern has been expressed by industry and MITI that the recently observed curtailments in investment and R&D expenditures may be compromising Japan's future competitiveness.

78. See, for example, "How Japan is Keeping the Tigers in a Cage", **Business Week**, 11 May 1992, and "The Tighter Lid on Japanese Technology", in Asia – The Next Era of Growth, Special Report, **Business Week**, 11 November 1991.

79. It must be stressed that the USA also faces an equally serious dependence on Japanese electronic components and manufacturing technologies, which is likely to worsen in the coming decade.

80. This trend is accelerating due to the rise of the Yen in 1993 and the domestic economic difficulties in Japan.

81. Dr. Kamal Hossain, Chairman, VAMAS Steering Committee, National Physical Laboratory, UK, "VAMAS: Current Status and Future Trends", 1992. I am indebted to Dr. Hossain for his generous assistance and information provided.

82. Dr. R.J.E. Glenny, Mr. J.A. Blair, Professor R. Tanaka, "VAMAS – An Independent Report", VAMSC (91)3, March 1991.

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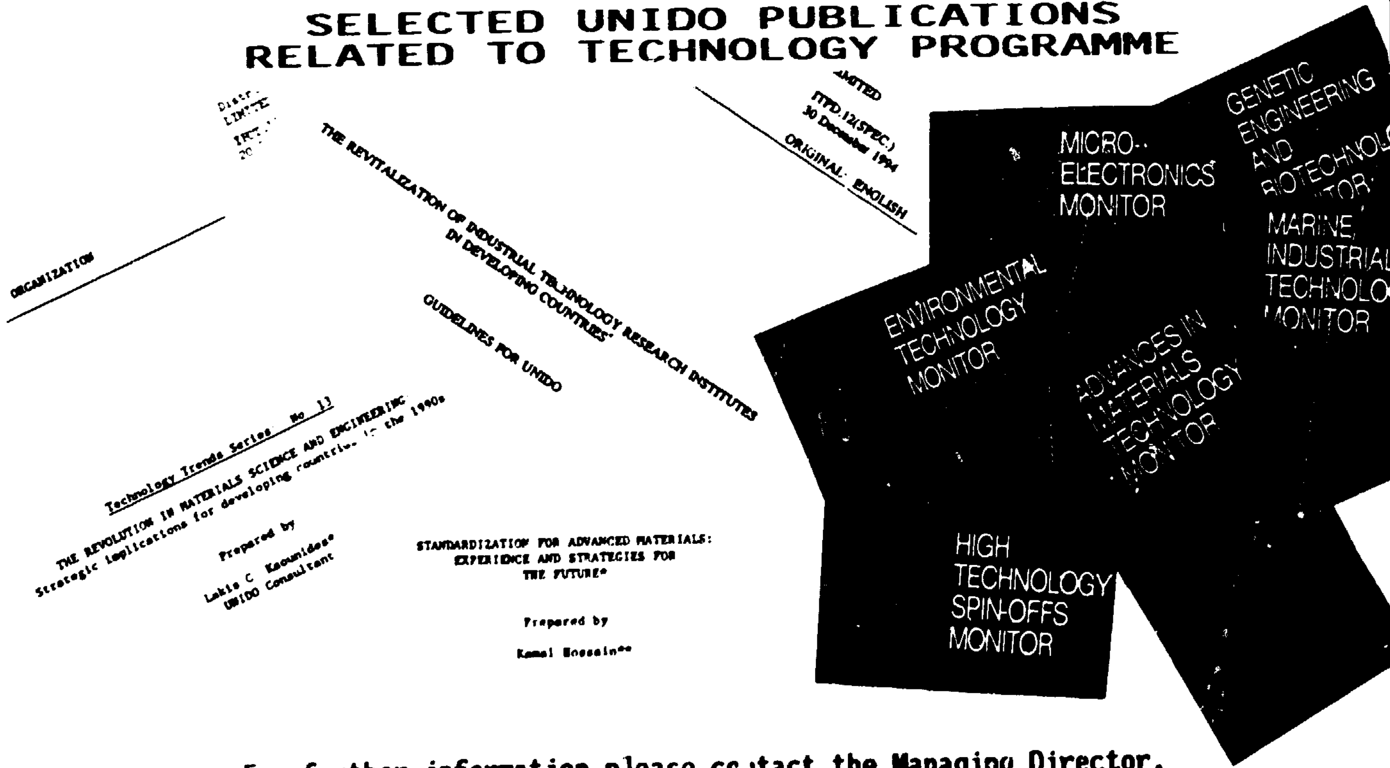

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