'Public and Private Sector Advanced Materials Strategies in the Late 1990s as Illustrated by the Case of Advanced Metals and Ceramics in Greece'

A Thesis Submitted to City University Business School, City University for the Degree of Doctor of Philosophy (PhD) in Strategy and International Business

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- DEDICATION -

To my mother and to the memory of my father and my uncle.

Especially to my mother and father I am and I will be obligated and thankful for the rest of my life.

- DECLARATION -

The author thereby declares that no portion of the work referred to in this thesis has been submitted in support of an application for another degree or qualification at this or any other university or other institute of learning.

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I.A. Kottakis
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ABSTRACT

The thesis investigates the conditions under which technological strengths can be transformed into corporate and industrial competitive advantages. The thesis focuses on advanced materials and advanced materials technologies and argues that this task can be achieved if a minimum set of practices is followed by firms, industries and nations.

The thesis builds a set of internationally accepted "codes of practice", which act as a globally accepted analytical basis, and tests them in the case of Greece and selected Greek industrial sectors (i.e. cement and consumer ceramic producers, ferrous and non-ferrous metals producers, the defence industry and the construction industry).

Given that Greece is an economy under transition (with weak R&D tradition and national system of innovation), the central research hypothesis examines whether the international "codes of practice" have to be modified first before being applied to each industrial sector and the national level or significant structural and institutional changes have to occur first in either the case of a specific industry or that of the national economy or both.

The combination of all the available evidence (literature review, evaluation and analysis of empirical research results such as in-situ data collection and interviews results) and findings lead to the conclusion that:

At *corporate level*, the international "codes of practice", can be universally and successfully adopted and applied even in the case of industrial sectors or corporations operating within weak national innovation systems or in environments significantly different from those where the "codes of practice" have been formulated. At *national level*, the international "codes of practice" *per se* are relevant as a coherent whole at the conceptual level, even in the case of transition economies with weak R&D infrastructure or institutional arrangements as in the case of Greece. The problem becomes one of policies and *institutional mechanisms* for supporting them and implementing them. This leads to the proposition that in the case of industrial sectors or corporations operating within weak national innovation systems and *especially* in the case of transition economies with weak R&D infrastructure or institutional arrangements (national level), organisational and institutional changes *have to occur first* before these industries and economies become able to fully develop and implement complex and multilevel materials strategies in response to the intensification of global competition.

Abbreviations[1]

AM - Advanced Materials

AMPP – Advanced Materials and Processing Programme (US)

CAD - Computer Aided Design

CAM - Computer Aided Manufacturing

CEC – Commission of European Communities

DOC – Department of Commerce (US)

DOD – Department of Defence (US)

DTI – Department of Trade and Industry (UK)

EKVAN - Programme of Research Consortia for Improving Industrial Development (Greece)

EPET - Operational Programme for Research and Technology

EPSRC – Engineering and Physical Science Research Council

EU - European Union

FMS - Flexible Manufacturing Systems

GDP – Gross Domestic Product

GERD - Gross Expenditure for Research and Development

GSRT – General Secretariat of Research and Technology (Greece)

IT - Information Technology

JIT - Just in Time

MITI - Ministry of International Trade and Industry (Japan)

MOD – Ministry of Defence (Greece)

MR - Materials Revolution

MSE – Materials Science and Engineering

NARC - National Advisory Council or Research (Greece)

NCRDP – National Collaborative R&D Programmes (in Greece)

NICs - Newly Industrialised Countries

NM - New Materials

NRC – National Research Council (US)

NSI - National Systems of Innovation

OECD – Organisation for Economic Co-operation and Development

[1] The list includes the most frequently used abbreviations.

PAVE - Industrial Research Development Programme

PENED - Programme for the Enhancement of Research Manpower

R&D – Research and Development

S&C – Structure and Composition

S&P – Synthesis and Processing

SE - Simultaneous Engineering

SMEs – Small-Medium Enterprises

STA (Science and Technology Agency (Japan)

SYN - Co-Financing Programmes

TI - Technological Information

TQC - Total Quality Control

"Every Idea Goes Through Three Stages:

1. It's Crazy – Do Not Waste My Time.
2. It Is Possible But It's Not Worth Doing.
3. I Said It Was A Good Idea All Along!"

(Arthur C. Clarcke)

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CHAPTER 1: Introduction to the Field, Objectives of the Research and Outline of Methodology Employed

1.0: Chapter Summary

The objectives of this chapter are three fold:

i) To introduce, albeit briefly, the field of the present research and the aims of the research,

ii) To outline the objectives and structure of the research and present the methodology selected in order to meet the aims and targets of the present research,

iii) To present a condensed and brief overview of the available literature and identify the issues most important to the thesis.

Section 1.1 provides a very brief introduction to the research field. Section 1.2 presents the objectives and aims of the research and explains the reasons (rationale) why the specific area was selected. Section 1.3 is dedicated to a concentrated discussion of the existing literature and then presents a new method of approach to the complex materials field and its interactions with its "environment". This section is divided into three parts: section 1.3.1. presents some key works and their main contributions to the field; section 1.3.2 includes a condensed presentation of findings obtained from a number of recent studies and finally, section 1.3.3 provides a new approach to the materials field and a set of conclusions emerging out of a synthesis of the findings in section 1.3. These conclusions formulate the point of reference for the formation and testing of the study's main hypothesis and the basic outlines of the theoretical part of the thesis. Section 1.4 provides a brief presentation of the structure of the thesis including a summary of the function of each chapter in the thesis. Section 1.5 briefly explains how the aims of the research were met (methodology). A full-length methodology report is provided in Annex 1.1. Finally, the chapter ends with Section 1.6 which contains comments on the main limitations of the present research and section 1.7 which provides a summary of the basic guidelines of the thesis.

1.1: Introduction of the field

The word "material(s)" originates from the word "matter". Both of them have the meaning of corporeal, or else something more or less *necessary* (Nuttall's Standard Dictionary). According to another approach, material(s) is "that of which *everything* is made, or anything of "*substance*" (Hornby, A.S.: '*The advanced dictionary of current English*'. Oxford University Press).

The stages of human civilisation, and hence the related technological, cultural and socio-economic characteristics of each era (see **Table 1.1**), were inextricably connected to materials and especially to the human ability to deliberately transform them and alter their properties (a process called today *Synthesis and Processing*) in order to serve specific needs and applications[1].

Until recently, most materials *per se*, (apart from precious metals) were regarded to be of little value because they are rarely final products. Thus, their strategic importance for technological and economic competitive advantage is not immediately apparent and has been seriously neglected (NRC 1989, Hondros 1986).

In modern times, it has become clear (see chapters 2 and 3) that progress in almost all technological areas is materials constrained and critically depends on progress and solutions offered by materials technologies and the Materials Science and Engineering (**MSE**) field[2]. Simply put, there is almost no physical, chemical or engineering mathematical formula where the natural, physical, mechanical and other properties and magnitudes of materials do not have a strong part and influence on the outcome. Daimler-Benz (1994) argues that *"...All improvements in cost, quality and performance of products and processes are materials related."*

Thus, materials technologies emerge as a group of enabling technologies and materials competencies emerge as critical determinants of competitive advantage at both corporate and national level because they have a direct impact on issues such as technological innovation, employment, trade, and industrial and economic growth.

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[1] Some authors suggest (e.g. Clarke 1979) that the classification of successive ages or epochs in civilisation, should be based upon knowledge intensity employed to alter the properties of the materials used because this provides the only objective basis. According to this classification the scale is defined approximately by: I - Stone tools, II - Metals: the use of fire, III - Writing, handicrafts, ships, IV - Steam power, basic modern science, V - Atomic power, information power, space travel, VI - Complete matter conversion to energy, transmutation of all elements on an industrial basis (efforts today - possible future?)

[2] I.e. dramatically improved existing materials, new materials with advanced performance, materials tailored for specific applications, new or improved synthesis and processing (S&P) procedures and technologies and new testing, characterisation and modelling technologies.

Several corporations, industries and governments around the world have identified materials related capabilities and competencies as crucial for current industrial and national competitiveness - hence for future economic and industrial growth - and they have developed the requisite materials strategies and materials R&D programmers in order to assure long-term technological advancement and economic competitiveness.

Time period / Year	Event
100,000 BC and before	Crude stone, flint & iron pyrite: mastering of **fire**.
20,000 - 10,000 BC	Elaborate stone, wood, clay & pottery; tools and agriculture.
5,000 BC	Copper and Bronze
1,500 BC	Iron age
1,200 BC	Glass
430 BC	Paper
100 BC	Cement
1350 AD	Gun powder / cast iron
1450 – 1500 AD	**Printing**
1780 AD	Cast iron in extensive use / steam – engines and machinery
1860 AD	Steel, Portland cement, rubber
1880 AD	Oil / natural gas
1930 – 1940 AD	Alloy steels, plastics, refined chemicals
1940 -1960 AD	**Transistors,** first light alloys and super alloys, advanced polymers and composites
1970 – 2000 AD	Optical fibers, advanced structural aluminium and steels, high temperature superconductors, biomaterials, "smart" materials and intelligent systems, nanotechnology.

Table 1.1: Materials through time (Various sources).

1.2: Objectives and aims of the research

The central issue of the present thesis is the question of how firms, industries and national economies can remain competitive in a fast-changing, technology-intensive, competitive environment.

The thesis argues that the Materials Revolution (**MR**) and opportunities originating from the *integration* of MSE strategies into technology and business strategies (see chapters 3, 4, and 5) can provide - if correctly exploited – significant technological and business competitive advantages to both mature and emerging industries and economies.

The thesis argues that this task can be achieved if a minimum set of universally accepted practices and strategic approaches named by the thesis ***"codes of practice"*** is followed by firms, industries and nations.

These "codes of practice", though, are extracted from recorded international experience originating from developed and industrialised economies or from large multinational corporations which originate from within these economies. As such, both national and corporate strategies are related to well-developed organisational and institutional structures (*institutional frames*) which have influenced or contributed to the formation and implementation of these "codes of practice".

However, developing and applying advanced materials technologies and strategies in economies under transition (a Southern or Eastern European economy for example), or economies where the national system of innovation has many differences to that of developed Western or Far East economies may prove to be a very different matter.

CENTRAL HYPOTHESIS

The critical question of how relatively small industrialising nations or economies under transition (and their critical segments of industry) with weak R&D tradition and / or weak industrial or institutional structure and technology infrastructure networks and linkages can respond to the Materials Revolution challenge still remains largely unexplored in the literature.

> The ***Central Hypothesis (H1)*** of the thesis is that in these cases, **either** the international "codes of practice" have to be modified first before being applied to each industrial sector and /or national level **or** a significant structural and institutional change has to occur first.

In order to test the hypothesis the thesis first builds a set of internationally accepted "codes of practice" which are used as "testing tools" (or analytical framework) and then tests them in the case of Greece, arguably a typical example of an economy with weak technological infrastructure, industrial basis and national innovation system. This is achieved by "testing" current public and private Greek materials strategies against the internationally accepted "codes of practice" in order to reach a list of findings, conclusions, and recommendations for future materials strategies in Greece.

The main part of the study comprises:

- An identification of the key characteristics ("codes of practice") in materials science, engineering and technology, and their implications for technology and business strategies at corporate (response of private industry) and national level (role of the government).
- An examination and analysis of the response of selected major industrial sectors critical for the Greek economy (i.e. private materials strategies) including an analysis of level of awareness, strengths, weaknesses and abilities to deal with the emerging challenges.

- An examination and analysis of the Greek national response (i.e. role of public sector / national materials strategies) to the Materials Revolution challenge including strengths and weaknesses, the identification of national priorities, and the ability of the national innovation system to deal with challenges posed by the MR upon major, critical for the Greek economy, industrial sectors (Part II – chapters 8 and 10).

An *additional issue* addressed in the first part of the study (identification of "codes of practice") is the question of which are the appropriate mechanisms, incentives and institutional arrangements for financing (or supporting the finance of) long-term R&D activities aiming at the development and application of successive high technology materials generations. The question, which is pertinent to the research aims of the thesis, also has a wider interest. Even if it is feasible to develop a materials technology strategy who will implement and finance it. In the materials case, the literature review and the field investigation strongly indicated that the issue acquires particular importance in this and any similar technological field, especially in the case of small countries with small or weak domestic financial markets. Therefore, the thesis dedicates a chapter (Chapter 6) and not just some paragraphs to the question.

Finally, the thesis concludes with a brief identification of areas for further research and a brief discussion of implications for materials and technology strategies in European economies under transition.

1.2.1: The necessity for the present research

With respect to the selection of Greece as a case study, the following considerations apply:

In recent years Greece has been subjected to strong competitive pressures originating from low-cost products coming from the Far East or Middle East, Latin America or Eastern Europe and the high-quality, high-technology products coming from the West and Far East. In addition, it is well documented (see chapter 7) that Greece is not any longer in a position to develop or possibly even retain labour intensive industries because the production costs (including energy costs) when compared with Pacific Rim or Easter European are eroding or eliminating competitive advantage in these industries.

A more viable, long run strategy for Greece (see chapters 7-10) may be to concentrate efforts on the development of technology-intensive, high value-added industries or services based on specialised human knowledge, creativity and skills.

Hence, in the case of Greece, the Materials Revolution poses both a threat and a challenge offering the opportunity to the Greek economy and industry to effectively respond and remain competitive in a range of existing activities as well as to create new activities and opportunities. These questions are of central importance to the framing of the research questions in the thesis.

Within this framework *there are no major studies*[3] (particularly at PhD level) dedicated to materials strategies with respect to Greek national and industrial needs. This is a *surprising finding* because Greek industry is directly or indirectly related not so much with final goods manufacturing but with materials or intermediate products production and fabrication in both specialised or bulk quantities. A key question is whether there exists a fully formulated and deployed national materials strategy in Greece at present, and this is where the present thesis can make a major contribution, both in terms of analysis and recommendations.

Additionally, although Greece possesses strong pockets of excellence in basic and applied materials research - mainly in public sector institutions and universities - many difficulties exist in taking full advantage of the opportunities offered by the MR for achieving sustainable industrial and economic development. Moreover, serious weakness in the industrial base and the national innovation system, which are related to the very large and predominant Greek public sector, point to Greece as, potentially, as a useful pilot study for other cases with similar characteristics (i.e. East European and Balkan countries).

With respect to the selected materials fields (metals and ceramics) the following considerations apply:

- Metallic and ceramic materials account for the overwhelming majority of the inorganic materials employed by all sectors of human activity.
- Greece has traditional strengths in these materials classes and the selected industrial sectors have a significant contribution to the national economy.
- Industries related to the production and use (e.g. construction industry, defence industry) of metallic and ceramic materials are usually mature industries[4]. According to international experience however, many of the most dramatic MR examples originate exactly in these industries.

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[3] The existing studies - mainly originating from the Greek literature - strongly focus on market or technical issues rather than on strategic analysis of materials issues as connected with corporate technology strategies and the national system of innovation.

[4] Greece does not have an established heavy manufacturing industry (e.g. cars, heavy machinery, electronics, electrical equipment) apart from the defence industry.

- The selection of these materials fields provides the opportunity for a thorough examination of Greek industrial sectors involved both with the production and consumption (e.g. construction industry, defence industry) of mainly metallic and ceramic materials (hence the title of the thesis) such as structural and consumer ceramics, cement, aluminium and steel.

Finally, the study does not particularly focus on organic materials, composites and chemicals for three main reasons:

i) Contrary to metals and ceramics, organic materials (plastics/polymers and, in part, composites) have attracted considerable attention from both the business and academic community thanks to the relationship they enjoy with the existing oil and chemicals industries in Greece. Many of the specialised materials studies refer to these groups of materials[5].

ii) The Greek plastics/polymers market, apart from two major industrial units, is extremely fragmented and mainly consists of SMEs (ICAP 1990 - 1996) which rarely have a long term materials strategy.

iii) The chemicals industry would require special technical/scientific knowledge which, unfortunately, does not fell within the technical background of the author.

However, the MR has strong relevance to these fields, which although of importance to Greek industry, may not have been examined even by the authors who have studied them. This could be the subject of another thesis and a good opportunity for further research.

1.3: A review of the existing literature and a new approach to a complex field

1.3.1: A review of the existing literature

The literature around the MR and its far reaching strategic, technological and economic implications can be classified into two main categories:

The science - engineering literature which is abundant but too technical for the needs of the present research, and the non-strictly technical literature regarding not just technical and scientific aspects but investigating interactions and implications of the

[5] E.g. Ktenas A. (1992): '*Transfer, diffusion and development of technology of petrochemicals, plastics and elastomers in Greece: The factors of successful transfer; absorption, development and R&D*'. PhD Thesis. National Metsovion Polytechnic, Athens.

technology such as maintaining competitiveness, R&D strategies, education, technology strategies and investment policies which is relevant to the present study. The paragraphs below provide a very brief overview of publications mainly of the second type and present their main point of focus and value to the present study.

Major Publications / Reports: Key reports and/or major studies or large R&D programmes reports dedicated to MSE issues produced by technology policy making institutions or large corporations and initiated by governments, research organisations, professional organisations, and large enterprises are the most valuable source of information. This style of literature is mainly in the areas of strategy and technology policy analysis, mainly of qualitative character and usually comes up with findings and recommendations of action. But since the field is relatively new and not completely defined[6] this type of literature provides the main source of information and reference in studies undertaken by individuals and in academic research. Some key work in this category of literature and their main contributions are:

I) *The UK Technology Foresight Programmes (DTI 1995)*: The report on materials is the first major report in U.K. which clearly identifies the two prevailing trends in materials strategies (continuous improvement of existing materials and/or new materials, breakthrough technologies), highlights areas calling for immediate action and explores scenarios for strategic response in this areas. It is also the most influential U.K. report in the 1990s to underline the importance of testing and evaluation as a common necessity to all materials sectors and interrelated technologies and to highlight the continuing importance of traditional materials such as steel and aluminium. With this report the U.K. officially recognised the importance of materials as key factors for maintaining industrial competitiveness and of fundamental importance for many industrial sectors. Further, there are several other technology foresight reports conducted in Germany, Australia, Japan, The Netherlands, France and others which are summarised in the Technology Foresight Volume 5*: A Review of Recent Overseas Programmes;* UK Office of Science and Technology 23/5/95.

II) The US National Research Council (NRC) study: '*Materials science and engineering for the 1990's: Maintaining competitiveness in the age of material'* (NRC 1989). This is a fundamental report fully dedicated to materials technologies and their integration with the industrial and economic environment. The research committee evaluated the impact of MSE by surveying its role in eight groups of industries (aerospace, automotive, biomaterials, chemicals, electronics, metals,

[6] The strategic implications of MSE technologies and their potential for technological and business advancement as well as their linkages with the other two generic technologies (electronics / information and biotechnologies) are not yet well understood and fully investigated (OECD 1990).

energy, telecommunications) considered important for commerce, defence, the national economy and prosperity and the public sector. It is the first report which identified and proved that materials inefficiencies and weakness (especially in the S&P field) in the 8 surveyed industries were one of the main reasons responsible for loss of competitiveness and industrial downfall. Industries with a strong materials integration and high R&D investments in the materials field (aerospace, biomaterials, chemicals) were found to be doing well whereas those who did not fulfil these requirements (automotive) have displayed increasing trade deficits contributing to the national economy's trade deficits. It illuminates the nature of the MSE field and calls for special attention to S&P activities for all of the eight surveyed industries. The committee also underlined the need for a national initiative in building and enhancing domestic materials capabilities and underlined the crucial importance of R&D in the field. It also called for co-operation among universities, industry and government. The report also focused on the importance of education policies, infrastructure capabilities and needs, and R&D time horizons. The report was extremely influential in the subsequent development and implementation of the Advanced Materials and Processing Programme (AMPP) under the Bush and subsequently, the Clinton Administrations, which continues until today. These findings were supported and supplemented by the findings of two other reports:

III) The US Department of Commerce study on the competitiveness of US technology: '*Emerging technologies: A Survey of technical and economic opportunities*' (DOC 1990) and the "*Critical Defence Technologies*" (DOD 1990) study examined by the US Department of Defence. These reports, each from a different perspective, defined MSE as a group of strategically important technologies accounting for a significant percentage of the so-called emerging technologies, underlined the crucial role of materials in maintaining competitiveness of the industrial base, and provided lists of emerging technologies and areas of strategic importance. They pointed out that the most important technological sector in economic terms (out of the 12 identified sectors and technologies) is the "*new materials*" sector for which US sales of $150 billion were forecast for the year 2000. This is in agreement with Japanese reports on advanced technology, initiated by MITI and other bodies, which continuously target advanced materials as top priority in both short and especially long term projects. The US government reports also identify that MSE technologies are clearly a long - term issue.

IV) Selective *Fast / Monitor* reports and the *Brite /Euram* programmes. In Europe, some of the Fast / Monitor initiatives and especially the evaluation reports on the Brite / Euram programmes (which account for one of the largest in human resources and capital expenditure initiatives of the EU) are recognised to be the European official response and acknowledgement of the importance of materials, especially in terms of maintaining manufacturing (and services) competitiveness of European industry. The philosophy underlying these reports accepts that developments in the materials field have serious implications for the quality, performance and cost of products competing internationally. It is interesting to see how the R&D focus of these programmes shifts gradually from pure and basic research (Brite / Euram I) to applied research (Brite / Euram II) to research which includes aims of commercialisation and market competitiveness (Brite / Euram III), although this merging of basic and applied research is not officially recognised by the Commission in Brussels.

V) OECD contributed in this area with the report: '*Advanced materials: Policies and Technology strategies*' (OECD 1990). This is the only recent OECD study dedicated to the MSE technologies. It is probably unique of its kind as it summarises the OECD countries' national policies on advanced materials, recognises a world trend shaping materials strategies according to national needs, and investigates the MSE issues from the governmental and macroeconomic point of view. It also raises subjects such as international co-operation and standardisation problems[7] as well as other difficulties arising from efforts to interpret the MSE economic consequences, and places heavy emphasis on education policies in this area.

VI) Another influential report particularly strong in explaining the materials revolution and the materials integration with business, R&D, technology strategies and new management tools is the Financial Times management report on '*Advanced materials: Corporate strategies for competitive advantage*' by Kaounides (1995). This report (and other works of the same author) is particularly strong and original in investigating the connection between materials, management and manufacturing theories and trends (i.e. simultaneous / concurrent engineering) while explaining clearly the long term impact new materials will have on the competitiveness of countries and corporations.

VII) UNIDO 's work on Advanced Materials. The United Nations Industrial Development Organisation (UNIDO) has been publishing several reports and organising several international meetings on advanced materials and their implications for science, technology and industrial strategies since 1987. Many of the recommendations of these meetings have begun to be implemented in developing countries across Western Asia, the Far East, Latin America, and Africa. UNIDO has been publishing the Advanced Materials Monitor in the last ten years and in March

[7] The issue of standardisation as related to materials and technology strategies, has been overlooked by most studies in the area apart from few exceptions such as OECD (1990) and Kaounides (1995).

1995 it introduced a new *'Advanced Materials Technology Series'* (see *Advanced Materials in High Technology and World Class Manufacturing*, (Kaounides 1995a,b,c,d).

VIII) The Cohendet, Ledoux and Zuscovitch 1988 study[8] on *'New Advanced Materials: Economic dynamics and European strategy'.* This report contains a survey of materials economic dynamics and a detailed study of the effects of developments in new materials on industrial strategies in Europe. It also deals extensively with the AM definition problem and introduces the *functional - structural* materials definition and classification upon which much of that study's analysis is based.

IX) *'Japanese/American Technological Innovation: The Influence of cultural differences on Japanese and American Innovation in Advanced Materials'* by Kingery D. (Ed.), Elsevier 1991. This volume contains the results of a symposium held in the University of Arizona (December 1990) aiming to explore the role and impact of culture on advanced technology innovation and development taking advanced materials technologies as case-study technology. It is a unique publication.

X) *Specialised reports.* Many other reports are dedicated to specialised matters but the list would be too long to be analytically mentioned here. A typical example of the genre is: *'Advanced Composites: A profile of the International Advanced Composites Industry'* by Elsevier Advanced Technology (1994).

XI) *Individual authors.* Many authors have covered various angles of the MSE field (e.g. Hondros 1986, Humphreys 1992, Lastres 1993, Hane 1992, Kaounides 1992, 1994a, 1995a,c,d, 1996a,b, Lianos and Chorafa 1993, Asby 1987 etc.). Some of the issues which have been thoroughly investigated or simply touched are: maintaining competitiveness, economic growth, management and manufacturing principles, market opportunities, organisational structures, relation with other technologies, education, human resources, technological advancements R&D strategies, corporate strategies and strategic alliances. Their contribution is significant and their findings are integrated to support conclusions and findings of the present research in the chapters that follow.

XII) *Theoretical underpinnings literature.* This type of literature provides theoretical underpinning for a wide range of issues. Typical example is the *'Strategic Technology Management: Integrating product technology into global business strategies for the 1990s'* by Dussauge, Hart and Ramanantsoa (1992). The book argues that technology (in general) must become a central component of any strategy-making process and

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[8] Also known as the BETA group: Universite' Louis Pasteur, Bureau d' Economie Theorique et Appliquee (BETA). The study was commissioned by the European Commission and was updated in 1990.

facilitates the integration of technological concerns into the business strategies of organisations. It also takes a distinctly global perspective on its subject and addresses the economic, organisational and cultural implications of technology. In addition, many of the practical examples employed come out of the materials field. It is a valuable point of reference to the present study because it provides a solid theoretical background and framework for many of the issues examined under the scope of their correlation with the MSE field.

XIII) *Academic Works.* There is a relatively limited number (especially in Europe) of academic works and conference results. In addition, it was discovered that there is a very limited number of PhD theses in the area. The theses available are usually either too technical and empirical (e.g. Beauvais, M. (1987): *'The materials and process of the residential construction technology in 2015 AD. - Implications for industrial education'*) or they are related to other subjects (innovation) and materials issues are the special factor or the area of focus (e.g. Hane, G.J. (1992): *'Research and development consortia in Japan: Case studies in superconductivity and engineering ceramics'*; Lastres, H. (1994): *'The advanced materials revolution and the Japanese system of innovation'*.)

In general, academic works (including papers) take a more analytical and theoretical view whereas reports tend to be more often of executive character. Large scale works conducted by individuals tend to compromise the two styles. The following section presents some key findings in the literature on the main parameters / issues in the materials field and its strategic implications. A review of the technical literature and more specialised issues is reserved for Chapters 2 - 6.

1.3.2: Key issues arising from the literature

All the reviewed sources identified that globalisation of markets intensifies both domestic and international competition, while much of the competition intensification is technology based. As such, technology is increasingly recognised as a fundamental element for economic and business advantage (Dussauge et al. 1992, Rosenberg et al. 1992). In addition, NRC (1989) and Kaounides (1992, 1994a, 1995a,c,d) identify that we are currently at the early *but secure and irreversible* stages of a remarkable and far reaching Materials Revolution. It has become clear that technical and technological progress in almost all technological areas is materials restrained while advanced or improved materials and processes and their commercial applications are set to become a crucial determinant of the competitiveness of firms and industries in a global competitive environment.

A lesson drawn from *recorded* international experience is that several firms, industries and governments around the world have identified that the integration of MSE related capabilities - Synthesis and Processing skills in particular - into their technology and operational strategies is a crucial strategic asset for industrial and national competitiveness and a crucial determinant for future economic and industrial growth. Within this framework, four main sets of issues emerge and apply (keeping the analogies) to both corporate and national level:

- The need to create, maintain or enhance a minimum critical mass of "domestic" (in-house) materials science and engineering skills and capabilities including other related core competencies and supporting infrastructure,
- The need to supplement these in-house capabilities with carefully structured alliances and interactions (corporate level) or the development of communication links and information networks (national level),
- The need to link materials R&D to the needs of firm / industry / national economy in the context of integrated products or services and process development,
- The need to formulate corporate materials strategies as an integrated part of an overall corporate technology and business strategy according to in-house capabilities and existing and future needs, and,
- The need to formulate national materials strategies as an integrated part of a national technology and industrial strategy according to "domestic" strengths and existing and future needs.

Further the literature review reveals to additional points:

A) At corporate level, the above tasks are implemented through the development of complex and reciprocal relationships where materials strategies are completely integrated within technology and business strategies. Reversing the argument, technology and business strategies are frequently drawn on the basis of materials strategies. At national level, the above tasks are implemented through the development of complex and reciprocal relationships where materials strategies are completely integrated within national technology and industrial strategies aiming to support the well-being of national economy. Reversing the argument, national technology and industrial strategies are frequently drawn simultaneously with materials strategies. As such, materials strategies have become inseparable from technology and business strategies at corporate level and from industrial and national technology strategies at national level.

B) Research and Development (R&D) activities hold a central role in the implementation of these efforts, while links similar to the above apply between R&D strategies and materials R&D strategies. At corporate level, materials R&D is integrated into the overall R&D corporate strategies and design of corporate R&D portfolios always take account of materials R&D strategies. At national level, many countries choose to implement their national technology policies through national R&D schemes and activities. Materials oriented national R&D activities are an integrated part of the overall national R&D portfolio.

1.3.3: A new approach to a complex field

To understand the process of creating a materials strategy and the process of the integration of advanced materials strategies into technology and business strategies, requires a deep understanding of multiple and interrelated issues (or for some authors an "entity" of issues[9]), which include technological topics, strategy and business goals, R&D issues, organisational structures, the economic and business environment characteristics and even cultural and political influences.

From the author's point of view, the interactions of the MSE field with its environment, and the integration of materials strategies into technology and business strategies as a strategic response to competition intensification, indicate that the materials field and its environment are in a state of constant, reciprocal and dynamic interaction. This interaction can be implemented and defined by a *compact set of three distinctive but inter- related and constantly interacting levels of practices.* These sets of practices and their inter-relations are shown in **Figure 1.1** and comprise the basic parameters of the *"materials strategic entity":*

First Level: The "core" scientific and technological level: This includes strategies and activities which are dictated directly by the scientific and technological nature and character of the MSE field. They are the inflexible set of choices, strategies and policies dictated directly by science, engineering and technology factors in any materials effort and they are therefore involved in and influence all materials efforts at both corporate and national level.

[9] The concept of the materials "entity" is not new. OECD (1990), and others (Cohendet et al. 1988, Lastres 1993) identify the materials field and its interactions and implications with the technology and business environment as an "entity" which is not yet well-defined and fully explored.

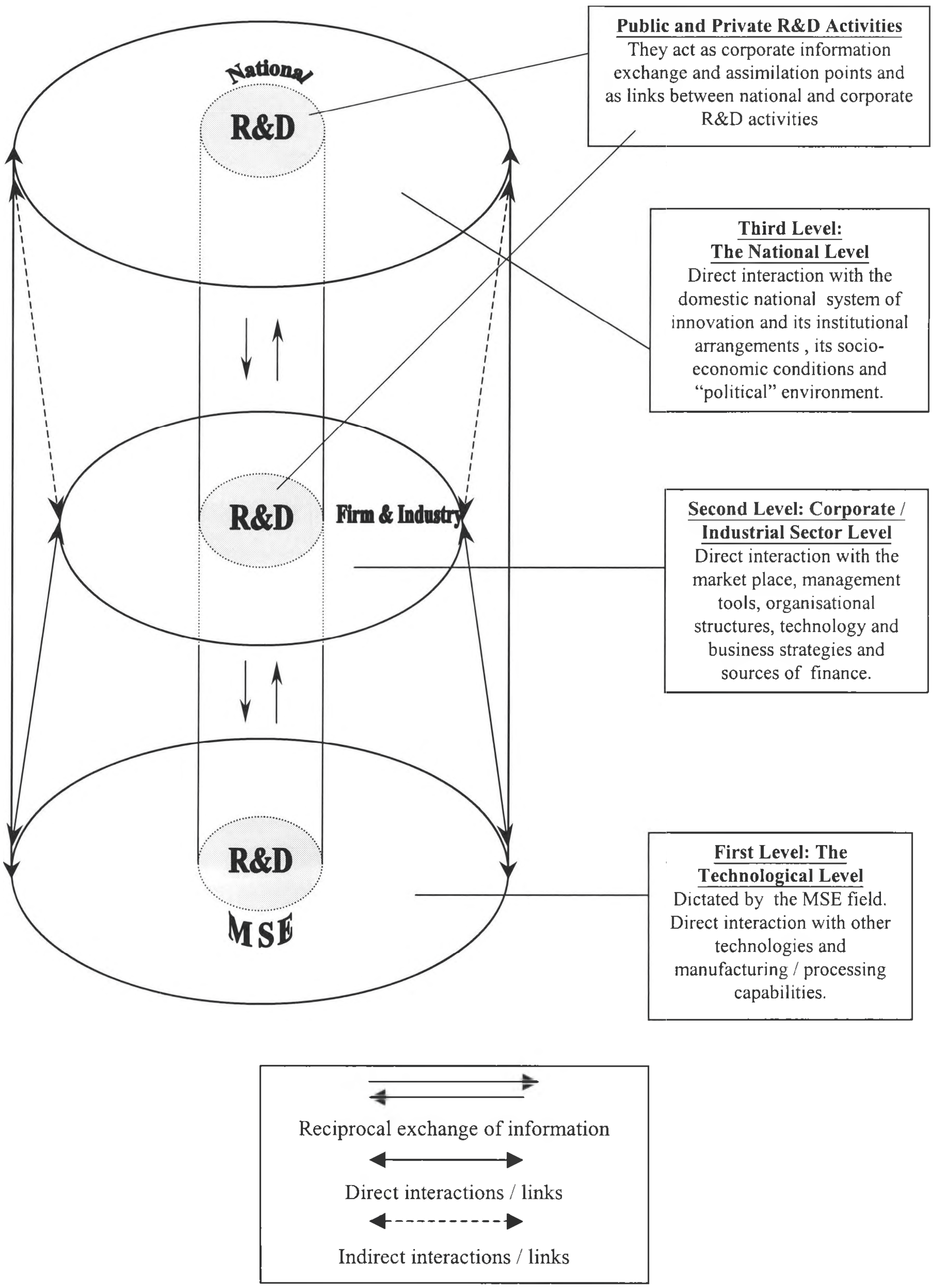

Figure 1.1: The Three Materials Science and Engineering Strategic Levels (Source: Kottakis 1999).

Second level: The corporate / industrial sector level: The second level of strategies applies to the interaction and integration of the MSE field into the technology, manufacturing and business strategy at the corporate or industrial sector level. Strategy formation at this level depends on "inputs" from the first level - existing or developing capabilities - and from the targets and directions set by the management. This level includes decision making and strategy formation of the R&D portfolio, internal supportive mechanisms, business objectives, response to market demands, strategic planning within the context of the opportunities offered by the MR and the MSE field.

Third level: National Strategies level: The third level includes mainly national strategies for materials technologies. These practices directly interact with the characteristics and arrangements of the national system of innovation and move mainly in two directions: i) they form a set of supporting strategies which aim to aid specific industrial sectors' / firms' materials and technology activities ii) they include national materials strategies tailored to meet the national economic and technological needs.

The importance of R&D: In the author's view, R&D activities and the way they are organised act as the focus point or the information exchange and assimilation point, providing a strong connecting link to the three strategic levels and the interactions and relations between them (see also chapter 4). Corporations and other institutions (e.g. public agencies, national research laboratories, universities) exchange information and interact with their 'environment' mainly through their R&D activities.

While there is still much to be done in order to explore and fully understand all the parameters and issues at work during the development and implementation of these sets of strategies, some basic strategic concepts, parameters and responses to fundamental issues (which shape each strategic level and the interactions between them) have already been investigated and identified in the literature.

In this study, for the first time, they are brought together as "***codes of practice***". These "codes of practice" have been *universally accepted and adopted* (with variations according to individual cases) by both the engineering/science and management / decision making and government circles having or attempting to create a well established materials strategy. The "codes of practice' take into account not only strategies for developing and employing materials according to specific needs, but *also the influence the environment can have* and how this influence affects these strategies in a dynamic and reciprocal way.

Thus, the "codes of practice" shape a system of interactive conditions reflecting basic strategic concepts and choices. International experience shows that **all these conditions are necessary - but not individually sufficient - to be met** in order to considerably increase the possibility of successful results when involved in any materials or materials related strategic effort. By having these "codes of practice" *as analytical guide lines* the overall materials strategies and their basic interactions can be understood, analysed and evaluated (within the frame of an overall technology and business strategy).

The "codes of practice" are identified in the First Part of this study (Chapters 2-6), and are used as ***"testing tools"***, upon which the findings of the field work and the empirical part of the study is analysed and compared in order to reach a prescriptive list of conclusions.

1.4: Structure of the thesis

The thesis is divided into two parts: Part I and II.

Part I provides a detailed examination and synthesis of the very basic "codes of practice", which act as the reference point and analytical framework upon which the empirical evidence and issues examined in Part II are based. As such, Part I aims to: explore the MSE characteristics, trends and strategies at both corporate and national level, identify the basic organisational and structural prerequisites for the development and implementation of corporate and national materials strategies, and, provide an outline of these generally accepted principles and strategies being formulated and implemented in this field. Part I comprises six chapters (including chapter 1).

Chapter 1 aims to provide a brief introduction to the area of research and set the main parameters of the thesis. As such, it contains a brief presentation of the literature review in the field and formulation of the research questions. It then proceeds to present the objectives and aims of the present research, as well as the structure, methodology and limitations of the research.

Chapter 2 first deals with the Advanced Materials definition and classification problem, providing working definitions and classifications, and then examines the characteristics, the technological nature, and the implications of the Materials Revolution and the MSE field. It then proceeds to examine some basic materials R&D characteristics and strategy directions (including business planning) determined directly by the scientific and technological nature of the MSE field and the selected materials groups. The reviewed considerations are *the set of inelastic factors* controlled directly by science, engineering and technology requirements/limitations. These inelastic factors influence the design and implementation of both corporate and national materials strategies. The "codes of practice" covering the first level of materials strategies (the technological level) are identified in this chapter.

Chapter 3 addresses the linkages between the materials revolution and industrial competitiveness within a general framework. The chapter first argues that intensification of industrial competition (on a global scale), is technology based. It then provides evidence that materials can provide significant competitive advantages and new business opportunities to a wide range of industries - if integrated to technology and business strategies - because, in many cases, technological advance and innovation and thereby business advance, is materials constrained. The chapter then focuses on business opportunities based on materials strategies. This is followed by a brief overview of the basic requirements and prerequisites for materials strategies at the individual firm level which leads to the analysis in chapter 4.

Chapter 4 addresses the issue of the materials revolution and its implications for competitiveness at corporate level (individual firm). The chapter explores and sets out the factors involved in successfully integrating materials strategies into corporate technology and business strategies (in order to provide competitive advantage). The chapter proposes that in order to maximise the benefits of this integration, firms must first comply with some basic management and organisational requirements and prerequisites. They include the adoption of specific manufacturing and management tools and practices (namely Kaizen and Simultaneous Engineering), the existence of R&D activities and strategies integrated into technology and business strategies, the ability to form external links or form technological alliances, the identification and management of technological core competencies and finally the adoption or development of communication mechanisms with customers and the firm's environment. The chapter addresses these issues at corporate level within the context of their interaction with the MR and the MSE field.

Chapter 5 is dedicated to the national response (at government level) to the MSE challenges and the parameters shaping a national materials strategy. The first part of the chapter examines the question of whether it is justified for the government to take action in order to support the development of long-term technologies and the research infrastructure or leave these issues to market forces alone. The chapter then proceeds to examine the form government action can take in the case of materials strategies and technologies and concludes with a brief overview of characteristic cases of national materials strategies and materials technologies infrastructure issues.

Chapter 6 investigates what are the appropriate mechanisms, incentives, institutional arrangements and time horizons for the finance (or the support of finance) of R&D in the development and applications of successive generations of materials (and other similar) technologies. Short-run **Vs** long-run investment strategies, issues of risk and return, availability of risk capital issues, sources of funding, supporting mechanisms and the role of the government and the response of the private sector are examined. The aim of the chapter *is not to provide an exhaustive analysis of these issues* but to provide a first approximation of answers which complement the findings of the five chapters above. Some of the chapter findings are incorporated in the "codes of practices" of the second and third level of materials strategies.

Part II is the main field research which took places mainly in Greece (*in-situ* investigation). It contains the empirical evidence and the conclusions of the thesis and includes five chapters (chapters 7-11). The questionnaire results and statistical analysis of the empirical evidence are in chapters 8, 9, and 10. Chapter 11 includes the conclusions, contributions and generalisations of the thesis and chapter 12 a brief list of recommendations.

***Chapter** 7* examines in brief the circumstances of the Greek economy and industry as well as the national R&D arrangements and the basic outlines of the Greek national innovation system. This is followed by an identification of industrial sectors of importance to the Greek economy and directly dependent on MSE technologies. Evidence of why the selected sectors are important is provided in this chapter. The chapter concludes with the provision of a set of observations and hypothesis tested by chapters 8, 9 and 10 which are the main empirical chapters of the thesis.

Chapter 8 addresses public MSE policies and strategies and the ways they are supported by the current arrangements of the national system of innovation. The presentation and discussion of the chapter is organised around five logical entities: national materials science and technology priorities, materials R&D institutional arrangements, infrastructure issues (education, standards and infrastructure), the role of universities and research organisations with respect to the formation and implementation of the national materials strategies, and issues of financing technological innovation (the role of Greek financial markets). Chapters 2, 5 and 6 provide the necessary analytical background for this chapter.

Chapter 9 focuses on the examination of the response of the Greek private sector to the MR challenge and investigates in more detail the response of the selected industrial sectors in terms of materials strategies as related to technology and business strategies and the operational environment of each sector. Both materials users and producers and their interactions are examined. The presentation and discussion of each reviewed sector is organised around six logical entities: corporate/technology priorities, R&D capabilities and arrangements, materials activities and strategies, management practices, technological linkages and collaborations, and interactions with national policies. Chapters 2, 3, and 4 provide the necessary analytical background for this chapter.

Chapter 10 is a relatively brief chapter. It examines the quite successful participation of Greece in the European Union (**EU**) materials collaborative programmes - mainly the materials oriented BRITE / EURAM programmes. Brief comparison of the Greek materials policies with the EU trends also takes place in chapter 10.

Chapter 11 brings together the main findings of the thesis (both theoretical and empirical) and provides a list of conclusions on Greek private and public MSE strategies and on the central hypothesis of the thesis. The chapter concludes with the identification of opportunities for further research and a list of contributions made by the thesis. The implications or generalisations of the findings for other economies with national systems of innovation and state of socio-economic development similar to Greece are also identified.

Chapter 12 provides a list of recommendations on private and public MSE strategies (including identification of materials priorities, infrastructure and other related technology policy issues) compatible with the current Greek domestic technological capabilities and characteristics within the national system of innovation.

1.5: Methodology

For presentation reasons the full and detailed report on the thesis methodology is given in **Annex 1.1.** For similar reasons lists with general information about the participants (interviewed or reviewed companies, institutions, universities, public agencies and other organisations) are also reserved for **Annex 1.2**. What follows is a summary of the basic lines of the employed methodology.

Basic guidelines: following the preliminary literature review and formulation of the research hypothesis and proposal under the title:

'Public and Private Advanced Materials Strategies in the late 1990s as Illustrated by the Case of Advanced Metals and Ceramics in Greece'

there were three major requirements to be taken into account:

The first was to formulate and build the "codes of practice". The second was the need for a balance in the empirical part of the research ensuring that the views of all the involved parties (and the interactions between them) had been adequately recorded and analysed. The third called for a detailed examination and analysis of *the viability and originality* of the research tasks.

In order to answer the above questions a literature investigation as well as a first preliminary *in situ* investigation in Greece was undertaken. The main aims were to obtain and/or to secure access to information and data and to establish contacts with "key" people in corporations, universities, governmental agencies and organisations who have knowledge of the field (managers, CEOs, professors, advisors, government administrators). The results of this preliminary investigation confirmed that the empirical tasks set in the thesis could be achieved. In addition, by investigating data bases regarding relevant information, recorded MPhil/PhD studies and other academic works[10], the availability of literature and the *originality* of the *research was verified.*

Having resolved these issues, the study adopted a *triangulation approach which includes a combination of desk work and field research* as the most suitable methodology approach.

Based upon this methodology model, **Part I** aims to present a globally accepted analytical basis ("codes of practice") and heavily depends on desk work and secondary sources of data which includes literature gathering and evaluation of recorded experience and available evidence. The "codes of practice" have been extracted after careful evaluation and synthesis of the available literature and information sources[11] and serve as a reference point and testing tool (or variables) of the study, reflecting internationally accepted common patterns of materials strategies. This information is also used, to a certain extent, to check the validity of the findings of the field research.

Part II mainly relies on field research results and primary sources of information, that is the analysis of qualitative and quantitative results emerging from the field research conducted in Greece (mainly data collection and interviews). Although the information obtained from companies and governmental officials is regarded as essential, supplementary information obtained by the other sources (i.e. "Grey literature") provided much insight into the materials strategies and tendencies in Greece. The character and the main activities of each interviewed institution are summarised in **Annex 1.2.**

[10] Including Greek MPhil/PhD studies.

[11] In deriving the "codes of practice", apart from academic sources, the thesis draws on the most authoritative strategy reports and sources of national engineering, scientific and technology policy-making institutions in the USA, Europe and the Far East.

The Sample: First, in order to achieve sample homogeneity and representativity and secure results compatibility and comparability a number of sample eligibility criteria were put forward (see Annex 1.1). Then, in order to established contacts and make appointments a two months preparation period was involved including a second travel to Greece. The results of this effort are reflected in the participation of 42 organisations and a collection of 57 interviews (most of them face-to-face interviews) carried out during a third travel to Greece (duration of three months) and a large volume of documentation and internal information.

Type of Institution / Organisation		**Private**	**Public**	**Total Number**
Firms / Companies / Industrial Groups[12]	Manufacturers & Materials Producers	12	2	14
	Defence Related Companies		3	3
	Construction Companies	3		3
	Construction Consortia[13]	1		1
Research Institutions			3	3
Universities[14]			4	4
Public and / or Governmental Agencies			5	5
Financial Institutions	Banks		2	2
	Venture Capital Companies	3		3
Professional Associations[15]		2		2
Other Bodies / Experts		1	1	2
Total		**22**	**20**	**42**

Table 1.2: Classification of organisations / industrial groups, construction consortia and experts which have accepted to participate in the research[16].

Table 1.2 (Table M2 in Annex 1.1) shows the range of the 42 institutions and Annex 1.2 provides general information about the participants and their activities. As can be seen from Table 1.2 the total number of financial institutions, public and governmental agencies, research organisations and professional associations account for 21 out of a total of 42 institutions. The manufacturing and production sectors cover the other 21 institutions.

The materials producers or users (individual companies, consortia and industrial groups) account for 21 institutes. From these 21 companies / industrial groups 11 are materials producers (6 ceramic producers and 5 are metals producers) and 10 are

[12] Three industrial consortia are included.
[13] The construction consortium under question is the consortium for the Athens Underground.
[14] The number 4 indicates that participants from academia come from 4 different Universities.
[15] Technical Chamber of Greece and Institute for Economic and Industrial Development (IOBE).
[16] Note that a single institution can include more than one interview (e.g.. Technical Chamber of Greece includes 3 interviews).

materials users[17] (4 intensive metals users, 3 intensive ceramics users and 3 intensive materials users (both ceramics and metals)). Nine companies / industrial groups have strong emphasis on ceramics (6 producers and 3 users[18]) and 9 have strong emphasis on metals (5 producers and 4 users) while 3 companies / industrial groups and consortia have mixed emphasis on both ceramics and metals (1 producer, 2 users). Finally 14 out of the 21 companies / industrial groups are under Greek control, 4 are subsidiaries of multinationals and 3 are under mixed control. **Table 1.3** (Table M3 in Annex 1.1) summarises the above information.

Company Type of Ownership and Materials Orientation	**Number**
Under Private Sector Control	16
Under Public Sector Control	5
Under Greek Control	14
Under International Control	4
Under Mixed Control	3
Materials Producers	11
Materials Users	10
Materials Producers & Manufacturing Companies	17
Construction Companies and Consortia	4
Companies with strong emphasis on Ceramics	10*
Companies with strong emphasis on Metals	10*
Mixed Emphasis	3
Total number of Companies / Industrial Groups	**21**

Table 1.3: Classification of Companies / Industrial Groups according to type of ownership and materials orientation.
* One Technological and Research Institution corresponds to each category.

Most of the names of companies, departments, or individuals who participated in the research are not revealed in line with a confidentiality agreement made with the interviewed participants. Key identifications are employed (see interpretation keys in Annex 1.2) .

The questionnaires: the questionnaires used during the interviews were based mainly upon the findings of the first six chapters and they test the basic ideas (codes of practice) developed in these chapters in the case of Greece. They were designed to be used in face-to-face interviews run by the author. They are presented in **Annex 1.3.** The aim of the questionnaires is to provide group results reflecting general tendencies and not to focus on analysing in detail individual firms / organisations. The results are then compared on a triangulation basis and analysed with respect to the theoretical background provided in chapters 1-6.

[17] Note that materials producers of say, metals, are intensive users of materials produced by ceramic producers. That means that the real number of materials users is much larger than 10.
[18] In addition, note that all the metals producers are intensive industrial ceramics and refractory users.

The questionnaires adopt a mixed approach comprising of closed questions (structured type of questionnaires) supported by open questions (semi-structured type of questionnaire) where the participant is free to develop his / her views and ideas. Particular effort was expended on both the content[19] (the nature and the way the questions are placed) and the technical design of the questionnaires. In order to ensure the quality and the focus of the questionnaire, two pilot studies were carried out during the second travel to Greece in summer 1997.

During the final interviews six basic types of questionnaires were employed tailored upon different types of institutions: (1) materials using and producing firms, (2) construction firms and construction experts, (3) research institutions, (4) universities, (5) public agencies, and, (6) financial institutions.

Results analysis: According to the preceding sections, the aim of the thesis **is to provide group results** reflecting general tendencies and not to focus on analysing in detail individual firms or other organisations. As such, the analytical unit from which conclusions are derived, is industrial sectors and national level indicators, not individual firms or case studies. A few individual case studies, presented in brief, were used to illustrate the analysis of the sector findings either because they make excellent trend and strategy examples or because some of the reviewed sub-sectors are monopolies or oligopolies[20].

On this basis, the empirical field results and data were initially subjected to **qualitative and discriminative** analysis[21]. A pattern matching analysis (patterns matching the "codes of practice") was employed which involved several steps including the familiarisation, conceptualisation, recording, cataloguing, and linking/ matching of concepts (Lastres 1993). Then, the results **were grouped** on the basis of industrial sectors and subsections in order to provide comparable similarities and differences of the trends prevailing or emerging in each reviewed sector. Final conclusions were derived based on the comparison of the findings between: public materials strategies and their implementation, metals Vs ceramics materials producers, and, materials final users Vs materials producers. Additional observations were made on the basis of the available findings (e.g. the influence of the type of ownership on the characteristics of currently applied MSE strategies). These results assisted in deriving conclusions and creating strategic scenarios in the final chapter of this study.

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[19] Brief pilot interviews with experts took place during the visits in Greece. The aim was to construct questionnaires close to the Greek environment (also see Chapter 7).

[20] Nickel and aluminium production sectors for example are dominated by only one company each.

[21] For the theoretical validation of the method see Yin (1994), Gill and Johnson (1994), and the other methodology references.

This process was occasionally supported by the employment of simple statistical analysis (when possible) and by secondary sources (when available such as the findings of the Greek technology foresight studies). Extensive quantitative or numerical analysis such as regressions or even simulations using dummy variables was considered but it was not possible to be applied for a number of reasons explained in Annex 1.1.

1.6: Research Limitations

Since the research has an interdisciplinary nature, it has to be designed in such a way as to take into account all the main parameters and simultaneously avoid two main threats: neither get carried away and diverted from the main aims by focusing on the wrong parameter nor remain descriptive or too general. Indeed, if attempts were made to analyse the area in depth as one, holistic entity, it would be too vast to be contained in one piece of work. Therefore, given the limitations of time and the complexity and sophistication of the field under investigation, special focus had to be given to one or two predominant parameters only, shaping the most fundamental "codes of practice" of the involved field.

** The **technological** parameter and its implications and consequences attracts and concentrates most of the attention of the present research. The secondary issues are investigated in conjunction with their supporting role to the main research questions stated in sections 1.2 and 1.3. The fact that the findings can have a more general application and provide the basis for future research is regarded to be a positive contribution of the present thesis.

** The character of the research is much more qualitative than quantitative because apart from the objective obstacles - lack or incompatibility of data - most of the issues and parameters involved cannot be or are not yet quantified[22].

** Given that something similar has not been researched before, a lot of the field work has necessarily an exploratory character. However, there are a small number of studies

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[22] As stated very clearly in the OECD study of "*Advanced Materials: Policies and Technological Challenges*" (OECD 1990) access to data bases containing homogenous information with an international scope is crucial. This information (R&D, investment, national budget) is for the time being *extremely patchy* and *often not comparable*. Moreover, the statistical categories used so far to describe the industrial scene are not the right instruments for assessing the developments connected with the emergence of advanced materials. The above mentioned data bases are required for in-depth economic analysis but they are simply not available. Experts recognise that a greater effort to collect and harmonise data would be particularly useful both for the public sector and the industry. However, it is essential for statisticians to be aided in their task by materials experts (OECD 1990).

examining issues such as the management of technology in Greece and general R&D policies and tendencies within the Greek institutional and innovation system. The findings of these studies provide some useful general guidelines and some very basic points of reference with respect to general technology strategy and R&D issues.

** With respect to the Greek case, most of the literature and the data involved is in Greek.

1.7: Basic guidelines of the study

According to the above, the major guidelines of the thesis are the following:

- The central idea of the thesis is the question of how firms and nations can become or remain competitive in a fast changing, technology-intensive, business environment. The issue applies to both individual corporations and to industrial sectors and national economies.
- Globalisation and internationalisation intensify competition. Much of the competition intensification is technology based.
- The MSE field, and materials-related technologies emerge as a group of generic and enabling technologies upon which further product, services and technology innovation and progress critically depends. As such, advanced or improved materials and materials technologies offer the opportunity for significant competitive advantages.
- To achieve competitive advantage, materials strategies have to be integrated within technology and business strategies or national technology and industrial strategies and this applies to both individual corporations and industrial sectors or national technology strategies aiming to support the well-being of the national economy. Research and Development (R&D) activities hold a central role in this integration.
- The integration of the MSE and the MR capabilities into technology and business strategies as a strategic response to competition intensification can be implemented and defined by a compact set of "***codes of practice***" which include three distinctive but inter-related levels of strategies addressing the technological level, the corporate level and the national level of materials strategies.
- The "codes of practice" have been formulated by combining experience extracted from corporate and national examples of industrialised economies of the West and the Far East. What is the case with transition economies or with firms,

industries and even economies with weak organisational and institutional structures or technology infrastructure (and hence firms embedded in these national systems of innovation and infrastructure frames)?

- The ***Basic Hypothesis*** of the thesis is that in order to successfully apply the "codes of practice" in the case of Greece (arguably a typical example of an economy with weak technological infrastructure and industrial base), and the Greek national system of innovation (and critical segments of its industry), either the "codes of practice" have to be modified first before being applied to the specific case, or a significant structural and *institutional change* has to occur.
- Several other related hypothesis are developed from the analysis in Part II and tested in chapters 7, 8, 9 and 10.
- To test the above hypothesis a combination of desk work and field research was adapted. The desk work mainly concerns the build - up of a set of “codes of practice”. The field work (data and information collection) is conducted through direct investigation in Greece including *in situ* information gathering and a set of interviews (see methodology). Questionnaires and survey methods are employed at this point.
- Conclusions and recommendations for private and public materials strategies in Greece, as well as implications for R&D and technology strategies in small European industrialising economies or with economies under transition are identified and discussed. Areas for further research are also identified.

CHAPTER 2: Advanced Materials and the Materials Science and Engineering Field: Their Nature, Characteristics and Key Technological and R&D Implications

2.0: Introduction

Chapter 2 is dedicated to the nature of the MSE technology, its requirements and implications and attempts to identify the "codes of practice" covering the first level of materials strategies (the technological level - see Figure 1.1). The reviewed considerations define a *set of inelastic factors* controlled directly by the nature, science, engineering and technology requirements / limitations of the MSE field. They are inevitably present in any materials effort and they are equally applied and affect all materials efforts (strategies) at both corporate and national level (hence underpin the analysis in chapters 3, 4, 5 and 6).

Within these lines, section 2.1 is dedicated to the problem of definitions and classifications which lies at the core of strategy choices offered by the MSE field. The section concludes with the provision of working definitions and classifications. Then, section 2.2, examines the characteristics, the basic trends, and the technological implications of the Materials Revolution and the MSE field. Section 2.3 and section 2.4 illustrate the nature of the MSE field and proceeds in an extensive analysis of *the materials tetrahedron* and its four interrelated elements: Performance, Properties, Structure and Composition and Synthesis and Processing. Particular emphasis is placed on the implications of the materials tetrahedron for the design and implementation of both corporate and national materials strategies. This is done by an identification of some key characteristics of materials R&D and some strategy directions (including business planning) dictated directly by the scientific and technological nature of the MSE field and the selected (targeted) materials groups. Basic requirements/prerequisites for materials R&D directly imposed by the nature of the "materials tetrahedron" are also identified.

The issue of how the nature of the selected materials groups influences R&D, materials and business strategy considerations is further examined in Sections 2.5 and section 2.6. The differences between structural and functional materials and between the choice to improve incremental materials or develop new materials as connected to business strategies, are employed as illustration examples.

The chapter ends with conclusions / recommendations which are turned into investigation issues and/or comparison points during the empirical part of the present study.

Also, chapter 2 includes three appendixes: Annex 2.1 provides a detailed review of the materials definition and classification issue, Annex 2.2 provides some additional working definitions and terminology and Annex 2.3 provides brief examples of the technical and business potential of advanced materials associated with recent developments in the MSE field and with selected industrial sectors or other groups of technologies.

2.1: Definitions & Classifications

2.1.1: The definition issue and working definitions

The materials definition and classification issue is a serious one because, apart from reasons of understanding and communication, if one cannot produce homogeneous information with an international scope using standard methodologies, then the available data indicating or measuring AM's issues will often be incompatible and not comparable (US Bureau of Mines 1989; OECD 1990; Fraser et al. 1988; Cohendet et. Al. 1988). This is not only a major problem for those working in the area but also gives rise to confusion in materials evaluation, selection and decisions making mechanisms and in understanding and managing the involved strategic implications.

Since the early 1980's, many different approaches have been used by the literature aiming to define and classify materials. For presentation reasons, they are discussed in **Annex 2.1**[1] (The Materials Definition Issue).

For the purposes of this research the following *working definitions* are used:

- **Advanced materials** are those usually high value-added, information-rich, probably experience-poor and technology-intensive materials which exhibit superior overall performance (functional, mechanical, economic) for a specific application or range of applications with respect to the performance of their predecessors (the material(s) they replace or have the potential to replace).
- **New Materials** are those materials which simply did not exist before and / or introduce new or far superior properties or exhibit new phenomena.
- **New Advanced Materials** are those materials which are both new and exhibit a superior overall performance for a specific range of applications.

[1] **Annex 2.1** makes a small contribution by offering comments on previous attempts at materials definitions and by *the provision of detailed justification* for the definitions employed by the thesis.

- **Incremental materials** are existing, known materials which are experience-rich but not information-saturated materials, which have not reached their theoretical limits and which retain a high potential for considerable properties and performance improvements and for employment in increasingly demanding applications (Kaounides 1995, Rolls-Royce 1995).
- **Conventional or old** materials are the experience-rich, information-saturated, and technology-mature materials which exhibit an acceptable but not outstanding overall performance for a specific application or a range of applications. They also have some common and distinctive market characteristics such as low price per weight and long service history.

The preceding working definitions are based upon the recognition of the fact that the term "*advanced*" materials necessarily entails a *relative*, dynamic and multi - dimensional concept. Therefore the word "*advanced*" material immediately refers to something improved, to a material with improved or better property(ies) and thus performance with respect to the one it substitutes. So, according to the author's opinion, **overall critical performance** -see **Box 2.1**- is the safest, sufficient and enabling definition criterion which defines AM in general[2].

Critical Overall performance: An "advanced material" which substitutes a conventional one for a specific application does not have to exhibit superior properties all-round. One property or a set of properties can be so crucial that it determines the selection of a material. For example, ceramics are inferior to metals in many aspects but they are much more corrosive resistant than any metal. Assume that corrosion resistance is the critical factor and fracture toughness the secondary factor. Until recently, ceramics could not satisfy the secondary factor. They were too brittle. So metals were used, sometimes with poor results. By improving ceramics' fracture toughness to acceptable levels the ceramics were still inferior to metals with respect to many properties but had outstanding corrosion resistance which is the critical factor for the specific application. That enables them to have *superior overall critical performance* and therefore they substituted metals. These particular ceramics are 'advanced' ceramics or 'advanced materials' with respect to the metals they replaced.

Box 2.1: Overall Critical Performance definition criterion. Kottakis 1999.

Exceptions to the rules, and blurred boundaries (which definition describes a material best) are inevitable. Nevertheless, for communication and compatibility reasons, the Advanced Materials (**AM**) term has prevailed in the literature. Materials and technology strategies, data collections, R&D programmes, university courses, conferences, books, journals and papers are usually enlisted under the AM terminology, even though the boundaries may not always be known.

[2] For further justification see Annex 2.1.

Finally, **Annex 2.2** provides some additional terminology definitions on themes such as basic research, applied research, innovation, generic technologies etc.

2.1.2: Materials Classifications

In contrast with definitions, *classification criteria* are tailored to specific information needs, they can be very precise and they usually express an agreement (sometimes tacit) on a specific issue. Some of the most frequently employed criteria and classifications are:

i) According to nature of microscopic structure: solid materials have been grouped into four basic classifications: Metals, Ceramics, Polymers (including plastics), and Composites. Lately there is a tendency to accept the existence of a fifth category of materials[3]; that is the semiconductors and the superconductors.

ii) According to main areas of application: that is materials for energy, defence, telecommunications, transport (aerospace, vehicles, automobiles, ships), construction, bio- applications, environment, information and multimedia.

iii) According to an important property or strategic function: that is classification according to the property that makes a material special or the property for which a material is mostly employed. There are materials for optomagnetic, electric, structural, thermal, mechanical, and chemical applications.

iv) According to fundamental differences in the manner they are used: This approach gives two groups of materials: the **structural** and the **functional**. The structural materials (i.e. steels, concrete, reinforced plastics, engineering ceramics) usually accommodate mechanical or physical properties whereas the functional materials (i.e. magnets, sensors, semiconductors) accommodate electrical, magnetical, or optical properties. The structural materials have passive behaviour and reaction to stimuli (they make or carry something). The functional materials have active and responsive reaction to stimuli (they do something). This separation has been adapted by Cohendet (1988), and most recently by the DTI's Technology Foresight Report on materials (1995).

v) According to the "generation" they belong to (Kodama, 1992): First generation materials are stones and woods, which are used primarily in their raw form. Second generation materials are copper and iron which become available by extracting components from the naturally available materials. Third generation materials are

[3] Due to their unusual electro - magnetic properties and characteristics.

plastics which are not available in nature but are synthesised artificially. The fourth generation of materials, drawing from chemistry, MSE, physics, biology and manufacturing will allow engineers to custom design new materials and designs by manipulating atoms and electrons.

Combinations of classifications are used, aiming to provide specific information and/or reflect the philosophy and the understanding perspective of the user. Within the above materials definitions, the present research mainly employs a combination of classifications (i), and (iv).

2.2: The Materials Revolution: basic characteristics and trends

During the last 30 years, it became increasingly apparent that we are at the early but irreversible stages of a remarkable Materials Revolution (**MR**) with far reaching technological and economical implications for both corporations and national economies (Cohendet 1988; NRC 1989; Kaounides 1995). Since the late 1970s, the systematic introduction of powerful computers, advanced instrumentation, and advanced mathematical modelling and simulation techniques into the semi-empirical materials field, has ushered-in a Materials Revolution in which we are seeking to quantitatively design materials based on fundamental understanding of the relationships between their structure, properties and performance. Some of the key characteristics of the Materials Revolution comprise:

** **Tailorability:** materials are tailored for specific applications. There is a growing ability to *structure and tailor* materials (by controlling their microstructure or crystal arrangement by advanced processing techniques) to meet specific applications. That is, either the creation of new materials with tailored properties or the continuous improvement of existing materials up to their theoretical limits. As such, materials are becoming increasingly integrated with the design and manufacturing process of components and final products[4].

** **Multi-disciplinarity:** To achieve tailorability of materials and processes, many different scientific and engineering principles have to be simultaneously involved. This necessitates a collaborative approach both between different disciplines and between different organisations (firms, research organisations etc.). Moreover, as the applications of materials have been expanding into diversified and in some cases inter - related industrial fields, research inevitably becomes interdisciplinary. As a

[4] Advanced Composite (AC) materials and their applications are typical examples of this trend: when loading conditions can be safely predicted, or, even better, designed, composites provide a unique opportunity to be accurately tailored, providing many advantages to the designer.

direct result, *boundaries* between materials categories and scientific disciplines in the materials field are becoming blurred or have ceased to exist. According to Allen (1995) of the E.S.R.C., "*one of the greatest joys of the materials community today is not having to think about metals, ceramics, plastics, and other materials as separate entities*". Indeed, the field of MSE has evolved along many parallel or intertwined paths facilitating the integration of the full potential of academic disciplines, R&D activities and the manufacturing / factory floor.

** **Creation of new materials for high performance applications:** When existing materials cannot meet specific requirements (either in terms of performance or manufacturing capabilities) new materials are developed to meet these requirements. The development of advanced composites or advanced ceramics are excellent examples of these efforts but in many cases their development took place at the expense of considerations of reasonable production and manufacturing cost. However, in recent years increasing emphasis is placed on cost / performance relations even in high technology applications; this ushers-in new challenges for materials design.

** **Dramatic improvement of existing materials:** Conventional materials and associated processing technologies are constantly being improved, becoming advanced materials and processes with respect to their predecessors. In many cases, the improvement can carry on incrementally or step - wise until a given material reaches its theoretical limits. In other cases the rate of properties and performance improvements appear to have exponential characteristics. World wide R&D trends indicate that a lot of interest is focused on the improvement of properties and performance of existing materials and finding new applications for them, rather than creating totally new materials.

** **Increasing materials variety:** These developments have led to an abundant variety of materials for both general and specific purpose applications. Clauser, (1975) reported that by the early 1970s several hundreds of times as many materials as in 1900 were employed. There were between 50,000 to 70,000 compositions and grades available and the average car had 4000 different materials while 70 years earlier less than 100 were used. Today, (1999) there must be a several fold increase in these figures. Indeed, the designers and engineers have no longer to rely on a specific given material for a product. Instead, several materials compete to provide a given function.

However, it is crucial to note here that *this must be seen as a result* of the increasing ability of MSE to "tailor" or "engineer" and combine materials into materials systems to meet a specific application.

** **Materials *per se* emerge as high added value products:** the introduction of AM into existing products means that the final improved "product" or component performs better and increases its added value because it is the result of a technology - intensive procedure and is information and knowledge-rich.

** **New relationships between materials users and producers emerge:** the ability to tailor materials and the need to integrate them into the design of the product and manufacturing process enables and necessitates the formation of new relationships between materials users and materials producers. Complementary technology-based alliances are emerging (see chapter 4) while producers seek to obtain manufacturing capabilities and users seek to gain deeper materials understanding. The need for efficient application of materials and the reduction of the lead time in the introduction of innovative materials solutions is a common underlying objective of these alliances.

The above characteristics indicate that MR has far reaching implications for further technical and technological progress and competitive advantage. But the MR has its origins in the MSE field and in the interactions of the four basic materials elements: Performance, Properties, Structure and Composition, and Synthesis and Processing. Every materials strategy has (or should have) its foundations on these four elements and the relationships between them.

2.3: The Materials Science and Engineering (MSE) field: Presentation and analysis of the materials tetrahedron

The origins: the problem of the inability of existing materials and processes to meet the ever rising performance requirements in many contemporary and high technology applications is a very old problem. The solution to this problem is either the creation of new materials possessing better combination of properties and performance, or the continuous and sometimes radical improvement of existing materials up to their theoretical limits, by utilising relatively recent advances in the MSE field[5].

The modern Materials Science and Engineering field. The modern MSE field **is a multi-disciplinary** field drawing most of its basic principles from many other scientific and engineering fields. It has its origins in the early 1930s when quantum theory and deep understanding of the classical theories of physics and chemistry came

[5] These two fundamental tendencies were sometimes antagonistic but today they tend to be complementary to each other. Each trend represents a philosophy, (or a strategic choice) and in conjunction with the MSE field and its intellectual foundation express the two major drivers of the MR.

into being. Until the late 1960s, the MSE field was dominated by empiricism and suffered from fragmentation and lack of coherence. But from the early 1970s onwards, the introduction of advanced instrumentation and later, computer power and advanced modelling and simulation techniques, provided deep insights into the atomic and molecular structure of materials and enabled the formation of a unified approach across all classes of materials.

According to Callister (1991) the MSE field involves the discipline of materials science, which involves the investigation of the relationships between the structure and properties of materials, and, the discipline of materials engineering, which involves the designing or engineering of the structure of materials to produce a determined set of properties to deliver the required performance of the material. According to the US National Research Council (1989), science in the materials field must include not only those areas whose utility is clear but also basic work – that is **materials research** - that provides fundamental understanding of the nature of materials. From the engineering point of view there is a constant challenge to transform new knowledge and principles into materials that perform in new or more effective ways.

Given that materials *per se* are of little value, both the British Engineering and Physical Science Research Council (EPRSC 1998) and the US National Research Council (1989) provided emphasis on the appreciation of the ultimate **end use** of materials and underlined that what **lies at the core** of MSE and what provides an **underlying coherence** to this diverse field **is the methodology** for developing materials for useful applications. Any methodology for **materials research** and / or for **developing materials** for useful and cost effective applications – that is any materials strategy **regardless of materials class**- has its foundations on the basic materials elements shaping the so called "**materials tetrahedron**" and on a fundamental understanding of their inter-relations and interactions. According to the British Engineering and Physical Science Research Council (1998) the **framework** (methodology) **for materials research**[6] consists of:

- An appreciation of the ultimate end use of materials and its implications for specifying materials performance targets,
- An understanding of the **structure** of the material required to produce the **properties** to deliver the required performance,
- An ability to produce the required structure, through a well defined and controlled **processing** technology.

[6] See: '*The Materials Programme - Framework for Materials Research*'. The UK Engineering and Physical Science Research Council (EPRSC), March 1998.

According to the EPSRC (1998) approach and the US National Research Council (1989) there are four fundamental but inter-related materials elements presented with **Figure 2.1** and **Figure 2.2.** These four elements include:

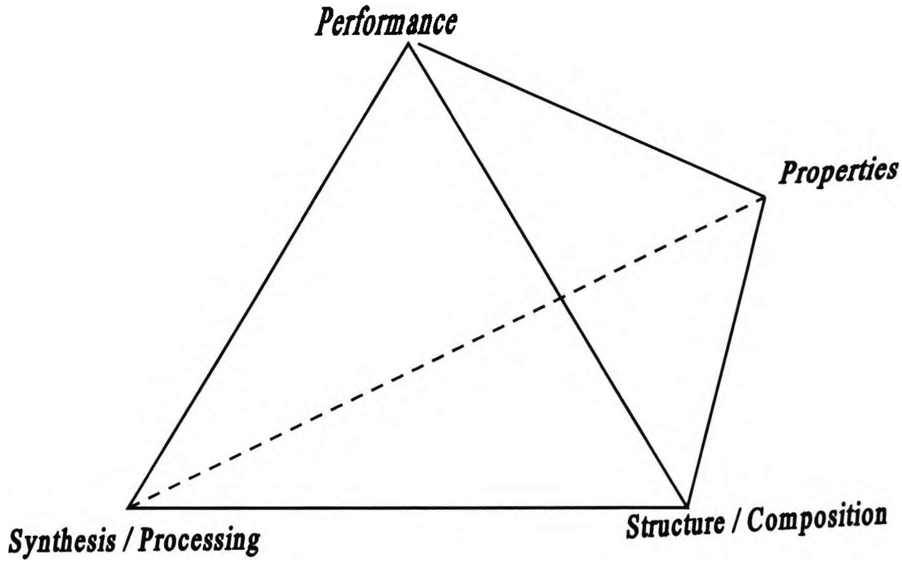

Figure 2.1: The four elements of Materials Science and Engineering. Source: NRC 1989.

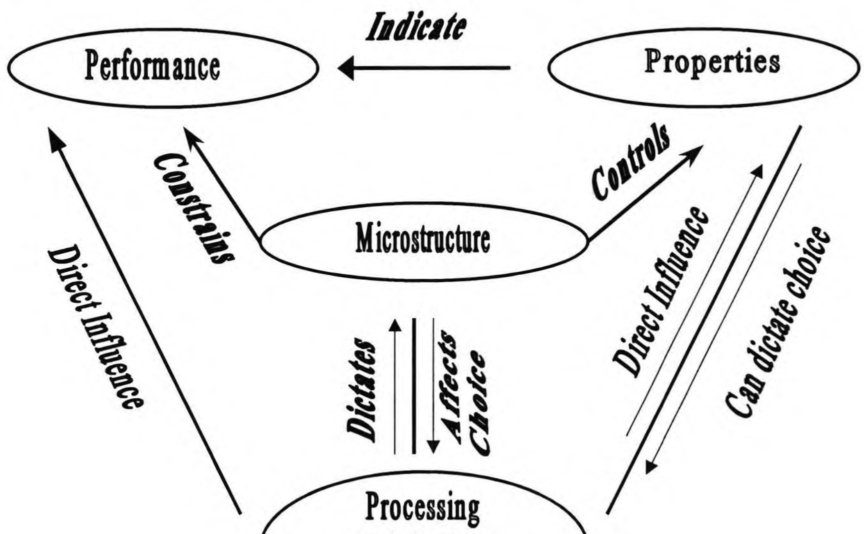

Figure 2.2: Inter-relationships among the four elements of the Materials Science and Engineering field. Source: Karbhary 1994.

- The *properties* or phenomena that make a material interesting or useful,
- The *structure and composition* (S&C) which includes the arrangement and the type of atoms or molecules that determine the properties of materials,
- The *synthesis and processing* (S&P), by which the particular arrangements of atoms or molecules are achieved,
- The *performance* of the materials, that is the measure of usefulness of the materials in real working conditions.

The present study fully accepts these authoritative views and builds its analysis on their approach.

2.3.1: The Materials Science and Engineering Tetrahedron

The four basic materials elements and their relationships and interactions are schematically presented in Figure 2.1 and Figure 2.2. Once a new target is set or a major scientific breakthrough occurs, the **full power** of MSE is needed to make something useful out of it. All the four basic elements of the materials tetrahedron must necessarily be involved if a successful result is to be achieved.

As such, deep understanding of the interrelations, interactions and connections among the four elements and of their individual significance, regardless of materials class and / or application is essential (NRC 1989, OECD 1990, Kaounides 1995, Karbhary 1994, EPSRC 1998). This approach places the performance element at the top of the materials tetrahedron and particularly underlines the S&P role.

Performance is the measure of usefulness of the materials in real working conditions. and it is the total sum of the synergistic action of the properties the material exhibits when stimulated in real working conditions[7]. Examples of measures of performance or performance requirements include lifetime, energy efficiency, safety, recyclability, durability, corrosion resistance, life cycle cost etc . Materials performance aims to serve strategic or commercial business objectives as it is the element where the inherent properties of a material link-up with product design, engineering capabilities, environmental and human needs and, most importantly, with the market place. Performance will determine profitability –hence competitiveness- and will provide a solid base for aggressive marketing and promotion campaigns. Profits can then be re-invested in R&D, better people, expanding or entering new

[7] Behaviour in service must not be confused with the laboratory performance. This is a good approximation but there is still a lot of R&D to be done especially when long-run performance is required. The real working environment is usually highly complex, involving multiple and often synergistic stimuli and forces.

business areas, and to develop new products, finance technology acquisition or transfers and so on.

Performance requirements however, are usually imposed by the final materials users whether they be specific industries or developments in the market place and the business environment. Given that materials performance strongly coincides with element, component or product design, and given that design is frequently materials performance and properties constrained[8], new opportunities for synergistic approaches between materials users and materials producers emerge.

Nevertheless, from the materials point of view, performance is constrained and determined by structure, properties and processing. Thus, performance research has to cut literally across all four elements of MSE and involve many intellectually challenging problems ranging from understanding micro-structural issues to macroscopic life-time predictions. For that scope, researchers increasingly seek to develop models that relate device performance to the properties and structure of the component materials. Advanced modelling and simulation techniques enable the accurate performance simulation of real working conditions prior to the building-up of the complete component. But for successful modelling, both analytical and experimental feedback and close co-operation between industry-universities is necessary. The old empirical methods for performance evaluation are time consuming and costly but they reflect gained experience and can provide the necessary feed-back which is not (and should not) be easily thrown away[9].

In brief, performance research is neither 'too macroscopic' nor 'too fundamental' (NRC 1989). It requires however, long-term and systematic commitment and investments justified by the fact that additional efforts to evaluate and predict the performance of materials in the context of their final applications have the potential to contribute substantially to problems of economic performance and commercial competitiveness.

Property(ies) of a material is the reaction or the behaviour the material exhibits when stimulated in one way or the other. Put differently, properties are the descriptors that define the functional attributes and utility of the materials which make them

[8] With design being the reflection and materialisation of socio - economic and market feedback and materials performance being the concentrated power of both the MSE and general science and engineering capabilities.
[9] According to some experts the old methods are still used because in many cases they are considerably cheaper than the new methods and this is related many times with the degree of relative experience. According to the author's opinion there is no bias of practices between empirical methods vs. knowledge models. Empirical methods constantly provide inputs in modelling methods.

interesting or useful and define if a material is worth the efforts to invest in time, capital and research and if the material has any commercial potential[10].

Materials research is by tradition strong in measuring, defining, improving or even discovering properties of materials enticing most of the materials oriented R&D efforts at the expense of the other three materials elements. Traditionally, properties improvement and / or new properties introduction is the initial focal. The reason for this attitude is rather simple: materials scientists and engineers had to depend on empirical or semi-empirical methods to improve a property or create a new set of properties.

Today, researchers verify the carefully pre-calculated properties and their expected values (of a pre-design material with carefully calculated structure and composition) rather than look to discover and measure for the first time unknown properties or property values. In simple words, the **ability to tailor** materials properties by tailoring their structure and composition to match existing or future designs and applications is rapidly becoming the rule in all materials classes. It follows that the needs for demanding and expensive instrumentation, analytical capabilities, flexible and well trained personnel, and sufficient funding are a prerequisite. But properties are the result of the structure and composition of the material.

Structure and Composition (S&C): A given material contains a hierarchy of structural levels, from the atomic to the macro- structural level. At all these structural levels, chemical composition and distribution may vary drastically. **Composition** can be the chemical composition of a material or the mixture proportion of the elements participating to the build of the material. **Structure** generally refers to the final arrangements of atoms (the lattice arrangement), or molecules (molecular chain structure), or grains, or combinations of all in micro-macro level when the material has reached and is set in an equilibrium position.

The nearly infinite variety of possible structures gives rise to the similarly complex arrays of properties exhibited by materials. Deep understanding of the origin of properties at the S&C level of the material and understanding materials at the atomic and molecular level enables materials designers to understand which specific structures will exhibit the desired properties and, consequently, tailor materials with specific properties in order to satisfy specific applications[11].

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[10] These definitions are rather indirect because most of the properties can be realised and measured only when stimulated. They have meaning only via quantitative measurements.

[11] Knowledge of the S&C in the grain or even atomic scale is also valuable for understanding interfaces between dissimilar materials (e.g. this is the biggest problem in composite materials) or for bonding materials together.

Following these discussion above, increased emphasis is given to the microscopic or atomic level, both in industrial research and in education. But R&D in the S&C element is particularly demanding in advanced, and hence expensive, instrumentation[12] and in sophisticated simulation and modelling techniques. If, however, atom-by-atom manipulation is ever to be achieved in real industrial conditions - and evidence suggests that this will be achieved via sophisticated synthesis and processing capabilities[13]- and not just in a laboratory, a high level of investment has to be maintained and sustained uninterrupted. The problem is that returns for the considerable capital investment the area requires are not usually visible in the near future. Project time horizons must be flexible and duration of projects can easily be 5 - 7 years, especially when new structures are under investigation.

But all materials internal structures and compositions are the result of S&P that has been applied to make a given material. It is good to have calculated which structure will exhibit the desired properties and thus provide the best performance, but the material must be produced in real conditions the way it has been designed, that is, its final structure must be the designed structure. This is where materials Synthesis & Processing comes in.

Synthesis and Processing are terms that refer to the control of structure at all levels, from atomic to macroscopic level and therefore they involve the development of processes to produce materials and components effectively and competitively. **Synthesis** is usually referring to the physical and chemical means by which atoms and molecules are assembled and composed. It can also mean the type of the fundamental chemical elements participating in the building-up of a material or the number of non - reactive phases or parts (mixtures) of a material. Synthesis largely predetermines the different types of final structure of materials. In order to achieve the desired structure (in any level) **processing** techniques are essential. Processing implies microscopic and macroscopic manipulations such as solidification, sintering, joining, mechanical forming, hardening, surface treatment, ageing and in general changes on a large scale including materials manufacturing.

[12] For example, a Tunnelling Electron Microscope which is able to provide insights into the atomic world costs £ 400,000 - £ 750,000 approximately in 1992 prises.
[13] Today for example, there is the ability to use MBE (Molecular Beam Epitaxy) in order to build matter atomic layer upon atomic layer of atoms for electronic devices. The prediction is that in the next 20 years we will able to build the first real 3 - D devices following an atom by atom building procedure (Scientific American 1995).

2.3.2: The importance of Synthesis and Processing

S&P determines if the desired structure of a material will be the calculated one and if this structure is made under cost-effective procedures. If that is so, then the combination of the desired properties will have been achieved; subsequently the overall performance of the material will be the desired one and then success in the market place is more likely.

It is important to underline that if performance is MSE's connecting link with design and the market place then S&P is the element which provides the connection of the MSE field with the manufacturing floor and the industrial base. If performance is the success measurement criterion and properties and structure the cause, then S&P is the **key factor** for the development and commercialisation of new or improved materials and **the enabling tool** to meet existing targets and introduce technological innovations. Hence, the links between S&P skills and manufacturing skills are critical determinants of technological innovation and of the speed with which basic research can be translated into commercial applications.

In addition, S&P capabilities are of special importance because they are the basis of using materials and materials technologies as an enabling generic tool and group of technologies in order to achieve:

i) The development of new products and materials as a response to emerging requirements,

ii) Improvement of old and conventional materials creating new markets and providing foundations for the r*ejuvenation and diversification strategies* of mature industries,

iii) The opportunity to fully integrate materials with the design and manufacturing process of components and final products (see also chapter 3 and 4) and finally,

iv) The opportunity to fuse complementary technologies, comprising the basis of many emerging technologies which in many cases are *materials constrained.* Technology fusion strategies are also largely affected by materials technologies and S&P capabilities.

In all cases, the development of **financially viable** S&P techniques simultaneously with the development of advanced or new materials is crucial for successful commercialisation of any material aiming to serve volume applications.

Despite its value however, the S&P element is the most neglected element of all four basic materials elements. First of all, an important but often overlooked factor of S&P

is the need for continued development of new machinery and equipment for experimentation and processing. Updated machine and equipment components are essential to improving S&P capabilities of any industry -notable examples include the markets for the semiconductor processing equipment- and the R&D abilities of any research institution or laboratory. But due to high development costs this point is usually overlooked. Moreover, pressing needs for R&D exist in every corner of the S&P element but many reports[14] identified a "traditional' weakness in R&D activities committed in the area resulting in loss of critical technological abilities and lagging behind established and emerging Far East technological powers (i.e. Japan and South Korea). Far Eastern companies are particularly strong in the S&P element and they perceive this strength as one of the main reasons behind their ability to commercialise scientific research with relative ease.

Further, the lack of support and attention to the area is notable both in the public sector (government, public laboratories and universities) and the private sector - industries and corporations - and it affects negatively the entire span of materials related activities.

This is a crucial issue because what use is a plethora of theoretical knowledge about materials when the ability to transform it into competitive products and services has been eroded or never developed?

Therefore, directing R&D funds to intelligent S&P of materials could have a direct impact on technological and commercial competitiveness. A coupling of experience with advanced modelling techniques would be, therefore, appropriate. To maximise the impact of such an effort, collaboration between industrial, university and governmental laboratories is also essential (DTI 1995, NRC 1989).

2.4: Common themes, considerations and requirements for materials R&D and materials strategies

The previous sections argued that any methodology for developing materials for useful and cost effective applications - that is any materials strategy, regardless of materials class- has its foundations on the basic materials elements shaping the "materials tetrahedron" and on a fundamental understanding of their inter-relations and interactions. Some special characteristics and R&D requirements of the four elements have already been discussed. With respect to materials R&D and materials technology requirements, the following considerations cut through all four materials

[14] (E.g. the US NRC 1989, US DOC 1994, Kaounides 1995, UK DTI 1995).

elements and all materials classes. Variations of approaches apply to individual cases (each material and each application has special "problems" of its own) but the general ideas remain undiminished.

** Among the four elements of the MSE field the following relationships apply: Performance is the total sum of the synergistic action of the properties the material exhibits when stimulated in real working conditions and it is the MSE field's connecting link with the market place. Properties are directly dependent on the structure and composition the material has. Structure and composition are the result of specific synthesis and processing procedures. S&P is the connecting link of materials science with the manufacturing floor. The relationship between performance - properties - S&C and S&P forms a close-fisted cycle (see also Figure 2.2).

** The MSE field is a coherent whole. If the early stages of drawing and defining materials strategies (both at corporate and national level) are not drawn on the basis of the requirements of the four basic materials elements, an implication of our analysis is that in all likelyhood these strategies will fail. Furthermore, if corporations and national policies are aiming to achieve a successful integration of their materials strategies with their technology and business strategies and maximise the benefits offered by this integration it is absolutely crucial to be aware of and properly address the above mentioned issues. Neglect of one of the four materials elements (and particularly of the S&P) can result not only in materials policy but also in technology policy failure with all the consequences that might have.

The above principles apply equally for both corporate and national materials R&D activities:

** At corporate level, since materials performance is the MSE field's connecting link with the market place, and given that S&P is the MSE field's connecting link with the manufacturing floor -where a synergy of all available technologies takes place- it follows that materials activities must be a consequence of, or a least be directly connected and integrated with the technology, manufacturing and business strategies of the corporation. As such, materials R&D activities must encompass all four materials elements, and materials strategies should be fully integrated to technology and business strategies of the corporation.

** Similarly, at national level, national materials efforts should be directly connected/integrated with national technology strategies and priorities and if possible act in support of national industrial strategies. As such, materials R&D activities must encompass all four materials elements and the national materials strategies have to reflect the needs and be fully integrated with the national technology and industrial strategies.This observation also underpins the analysis in chapter 5.

On the other hand, the multi-disciplinary nature of the MSE field imposes the following requirements on both corporate and national materials R&D efforts at any level[15]:

** **R&D activities covering the entire spectrum of all four elements are of paramount importance**. As the US NRC (1989) put it: '*If MSE is to remain healthy and productive, R&D addressing all four elements of the field and their interrelationships is vital*'. Special attention should be given to the performance and S&P elements because they are the most demanding and most multi-disciplinary elements of the four.

It must, however, be stressed, that concentration of efforts in only one of the four MSE elements is not advocated since it does not allow the full utilisation of the potential benefits arising from the strong interconnection between the four basic materials elements. As shown in Figures 2.1 and 2.2, each element has a strong influence on all the others and advances in materials developments and applications require that attention be *simultaneously* focused on the acquisition of multi-disciplinary skills across all four elements of the MSE.

** **Modelling and simulation skills:** The employment and intensive use of advanced instrumentation, computer power, modelling and simulation skills is of paramount importance for successful R&D in all four elements of the MSE field. Computer power, and advanced simulation and modelling provide powerful tools for improving and testing properties and performance, understanding S&C and making S&P affordable and effective in terms of production competitiveness and meeting environmental and regulation constraints[16].

Modelling and analysis skills applied through-out the organisation are of equal importance because the MSE field is gradually evolving into a fully quantitative field. Mathematical models are an effective communication language between different principles. For example, significant improvements in quality, efficiency, reliability and production cost are the results offered by a coupling of applications of analysis and modelling to all levels of MSE with analysis and modelling of other interacting fields. Taking the issue one step further, the UK Technology Foresight Panels, (DTI 1995), put particular emphasis on this point and underlined that gaining skills in the area is a capability **which can not be externally acquired**.

** **Instrumentation:** The regular up-dating, replacement or acquisition of new equipment (experimental apparatus) and funding for R&D in new equipment (both

[15] Government policies, university programs, R&D initiatives, industrial materials policies, etc.
[16] The critical importance of theoretical screening models and of process models (linking materials design to processing path and performance in real conditions) have been identified by the UK Technology Foresight Panel on Materials (DTI 1995), and the President of the Institute of Materials (1994) in London.

experimental apparatus and industrial machinery) is crucial for keeping research and production capabilities on the cutting edge.

** **Data and information availability:** Information diffusion mechanisms and compatible data and standards are crucial for materials R&D progress and for materials R&D commercialisation. Corporations can argue for commonly accepted standards and measurements while the establishment of information diffusion mechanisms and internationally accepted standards is in the domain of national policies, national innovation systems and international collaboration.

** **Human Resources:** Manpower and well-trained personnel is identified as the most important infrastructure aspect (both at corporate and national level), being the most demanding but rewarding investment in the long run. Creating a critical mass of highly trained and skilled personnel in materials technologies, able to cope with all four elements of the materials tetrahedron should be a priority for human resources at corporate level and a national educational priority at national level. Especially in the West, all four elements suffer from shortages of well trained personnel at both graduate and postgraduate level, with the S&P element suffering the most.

** **Synergistic and collaborative approaches:** The complexity of the MSE field and the complexity of its interactions with other technologies and the business environment necessitates multi-disciplinary approaches which usually take the form of multi-disciplinary teams within the firm and long-term, technology-based alliances and collaborations between corporations and/or between public and private sector organisations (e.g. between universities and corporations). The collaborations approach employed to support long-term and risky materials R&D projects tends to be a standard pattern of action in the MSE field (see also chapter 4).

** **Materials strategies and time horizons:** All reviewed sources[17] lead to the conclusion that the MSE field **is and has to be** a long-term issue. Seven to ten years time span is not an unusual requirement for materials R&D projects[18]. Short-term product development or R&D efforts, a wide-spread Western attitude, is proving to have an adverse effect on corporate, industrial and national capabilities in drawing effective materials policies and integrating them into their technology and operational policies. In contrast, materials related R&D activities at the national level have a long-term perspective in the countries of the Far East -especially when the aim is the development of new materials or new technologies. Similarly, corporations originating from these countries appear to follow the same attitude with respect to materials R&D time horizons and accepted levels of risk and cost. There are strong

[17] See section 1.6.1: Some important studies.
[18] Time periods for different development stages can vary from case to case but adding all stages together makes a long time period.

indications that this pattern is also enhanced and supported by a similar attitude in the financial institutions of these countries.

** **Supporting infrastructure:** Materials technologies require the existence of a supporting infrastructure at both corporate and national level. Materials R&D necessitates the involvement of the entire corporate innovation system at corporate level and the national innovation system at national level (see chapters 3 - 6).

2.5: Basic materials R&D characteristics: Structural Vs Functional materials

The discussion in this section focuses on key considerations of materials R&D which apply over all materials classes and application areas with relatively small variations and differentiations. These directions and general characteristics have a significant effect on the design of materials strategies and they are presented with respect to R&D considerations originating in the Functional Vs Structural materials classification and distinction.

Structural materials usually make or "carry" something. As such, their performance requirements are usually more complex than functional materials which simply have to "do or actively respond" to something. In addition, structural materials are usually made into components or products of some **considerable size** (compared to many functional materials such as semiconductors) which have to operate while exposed to multiple stimuli. As such, structural materials require longer **testing and development** times than functional materials, while the level of theoretical understanding of their structure - properties - processing relationships is not as clear as in many functional materials cases. The following reasons apply:

1 -- Development history: Structural materials discovery and development is traditionally related to mechanical and civil engineering rather than chemistry and science and until recently their development and improvement was the outcome of empirical or semi - empirical gained knowledge and procedures.

2 -- Complexity of purpose and performance: Structural materials are subjected to much harsher environment and synergistic stimulation whereas functional materials usually respond to and have to cope with limited or even unique or uni-directional stimuli. For example an aeroplane's flap is made out of a specific material which is subjected to set of loads, fatigue, creep, chemical attack (weathering), extreme temperature variations and even occasional impacts just to name a few principal stimuli. It must exhibit a combined performance to cope with all this synergistic agitation. On the contrary, a semiconductor - typical example of a functional material- has to respond to a very specific agitation: electrical current or magnetic field. Temperature affects the semiconductor's performance but every effort is made to remove unwanted environmental interference; semiconductors usually operate in environmentally controlled conditions.

3 -- Complexity of structure: Structural materials are rarely pure materials. They are usually mixtures of many elements or mixtures of materials which are in turn chemical mixtures or results of chemical reactions. Functional materials however, are usually pure substances (semiconductors) or pure chemical compounds or outcomes of chemical and /or physical reactions (superconductors, piezo - electric). It follows that for functional materials there are less parameters to be taken into account when a new material is to be made or an existing material to be improved.

4 -- The size effect: The size effect, first identified by Leonardo Da Vinci, simply says that small things are closer to their theoretical design and limits than larger ones aiming to serve the same purpose when made of the same material(s) and with the same S&P procedure. That is because small articles contain statistically less structural defects than large objects and because S&P can be controlled easier and more accurately for small objects through out their entire bulk, avoiding the introduction of imperfections or impurities, whereas in large entities this is many times more difficult.

5 -- Performance requirements: For the majority of their applications structural materials can still meet performance requirements while structurally imperfect, while functional materials have usually to be structurally perfect to do the job.

But performance requirements for structural materials are becoming more and more demanding. Structural imperfections for many applications (i.e. aerospace, power generation and utilisation, transport applications) are simply not acceptable while structural materials retain all the above characteristics.

As such, R&D efforts are mainly focused on properties and performance improvement coming out of advanced S&P control and of structural accuracy and purity concentrated on the phases and grain size level with the aim to reach the atomic level for these materials in the future. That usually takes the form of continuous improvements of existing materials and technologies up to their theoretical limits (which in many cases are not yet known). New structural materials tend to attract extensive R&D attention only when it is certain that the performance requirements are beyond the performance of any available material or the available materials cannot be reasonable cost.

Advanced instrumentation and computer power offer the opportunity to introduce analytical modelling, insight observation, and mathematical simulations to these complex systems, fill important understanding gaps, execute large scale performance tests and develop theories that provide *quantitative guidelines* for the development, design and S&P of structural materials.

For the reasons mentioned above, structural materials R&D requires longer periods of time for their development and particularly testing of their properties and performance as well as for their commercialisation and integration into components, products or manufacturing processes because it takes time until they are widely accepted.

It follows that cash-flow for R&D needs to be secured for a longer testing and development time and with respect to capital allocated to R&D equipment, structural materials are possibly more demanding than functional materials especially when it comes to mechanical properties and performance testing and evaluation.

Global competition in these materials is fierce but change has a rather slow pace. Substitution mechanisms of structural materials are usually slow and their development, testing and improvement are mostly based upon widely available technologies which push international players to adapt a rather conservative attitude, preferring to exploit existing technologies and pursue constant incremental improvements rather than risking a significant breakthrough which can be easily copied and reproduced by competitors.

Functional materials are mostly modern materials which are used to make components and products of rather small size or limited thickness. Their discovery is mostly related to scientific basic research and their development and improvement is the outcome of scientifically gained, quantified knowledge and procedures[19]. They have to respond to rather simple and not synergistic stimuli and contrary to structural materials whose properties and performance can tolerate some structural imperfections, performance of functional materials is mostly dependent on accuracy and purity of their structure up to the lattice and atomic level. As this was understood immediately, S&P methods and principles were developed and set simultaneously with the basic properties and performance R&D efforts. For functional materials, due to their relatively small size and limited variety of stimuli, it is possible to construct in real S&P conditions the desired structure which is usually the result of early employment of theoretical calculations, modelling and advanced instrumentation.

As a result, most modern functional materials are new materials, they have the potential to create new business opportunities and they require shorter development and commercialisation times than structural materials because of both sophisticated

[19] Scientific research, fundamental scientific discoveries (such as band theory, solid state physics theories etc.) and mathematical modelling and analysis preceded the development of many functional materials (e.g. semiconductors). On the other hand, most structural materials were, until recently, the result of empiricism.

S&P capabilities and of shorter testing times, due to reduced structural and stimuli complexity and the size effect involved. Commercialisation times can also be shorter than structural materials because change in functional materials is diffused and accepted faster than most structural materials. The basic research and structure design stage, though, can be considerably longer than that of structural materials because there might be no existing experience and no empirical rules avaliable.

R&D efforts on functional materials are equally focused on improvement of existing materials and on discovery of new materials and new processing techniques and more effective production methods, in terms not only of performance but of cost and efficiency.

Another important element of the R&D efforts on functional materials is the issue of compatibility, or how materials *interact* with one another. R&D efforts on the structure of functional materials are concentrated on the atomic level and they are very demanding in sophisticated and state of the art instrumentation.

Moreover, these materials and the process used to fabricate them are being pushed to their limits due to aggressive global competition aiming to control entirely the global market. That is because functional materials development and improvements depend on state of art technologies and instrumentation which are available to few (e.g. only 5 - 6 corporations have the ability to produce first rate silicon for semiconductors globally, and very few manufactures have the capacity to produce reliable and ready to use optical fibers). This has created a need for R&D on the fundamental limits of present technologies and on how these limits can be met with new, more effective, processing methods and what new materials or fundamental concepts will evolve to overcome these limits.

2.6: Materials Science and Engineering and materials technological trajectories: Improving conventional materials Vs Creating new materials

There are two primary trends in materials R&D which underline the two major prevailing technological materials trajectories and the opportunities offered in each of them. One has to do with the development of new materials or new advanced materials and the other with the improvement of incremental and conventional materials independently of class or categorisation.

Improving incremental materials. Incremental and conventional materials are materials with relatively well known properties and they mostly reflect the progress of a natural evolution of long employed, experience-rich materials. They are usually the outcome of empirical or semi-empirical production methods and therefore provide the opportunity to be pushed gradually and incrementally to their theoretical limits which are not always known. Typical examples are improved or new grades of steel and aluminium. Properties and performance improvement are based on recently acquired capabilities to accurately control the materials structure even for large volume pieces. By modelling and monitoring the quality and structural and design accuracy of the production process, the creation of a new generation of not just improved but *advanced materials* has been achieved. These materials have the experience of their predecessors and therefore the risks and costs involved in their employment are much smaller than new materials.

The R&D approach of continuous improvement of incremental materials is reflected in many world class companies with the most typical example Rolls - Royce. Rolls - Royce calls conventional materials *"incremental"* materials and their R&D policy reflects their choice to mainly push in the direction of incremental materials. Their aim is to maintain leadership in aero-engines production over the next 20 - 30 years mainly by improving and applying existing incremental materials. This attitude reflects the thinking of first exhausting the limits of existing materials and look for completely new materials only when this is absolutely essential.

Not all but most of the conventional and incremental materials belong to the structural materials category. They, and their related strategies, dominate many generic technical applications and will keep doing so, controlling and having the lion's share of all the general and "bulk" applications in the future. Most of the structural materials producers gravitate to the continuous impovement approach, and R&D expenditures and investments in new materials R&D tend to be restricted. Under this logic, R&D in "incremental" materials reflects a continuum from present to future and an attempt to direct future technological developments.

In addition, drastic improvement of existing grades of materials is the first step when an industry enters the technology race **for the first time** because the basic infrastructure (manufacturing line, experience, people and knowledge) does not need to be drastically altered (at least in the beginning). Further, by initially gaining stability in the market and gradually learning to exploit MSE capabilities integrated with their special requirements, corporations can then expand into new areas and novel materials.

With respect to time frontiers, these strategies offer the first strategic response to be followed by industries for remaining competitive in a short to medium time span, providing substantial opportunities for short to medium term profits which can then be invested in longer term strategies.

Strategies of this kind represent the conservative view of the two materials technological trajectories and therefore they are expected to lead existing technologies to their limits bringing them to maturaty and prepare the ground for new technologies. In many cases, the incremental or advanced materials development or improvement process can become the origin of diversification and rejuvenation strategies or provide a basis for technology fusion efforts (see Chapter 3).

Creating new materials and new advanced materials. New materials or new advanced materials are developed to meet extremely demanding applications, go beyond conventional performance limits and / or introduce new properties. As such, they usually offer many new opportunities for revolutionising existing technologies and / or creating new technologies and markets. NAM exhibit in many cases properties (and therefore potential applications) so tantalising nobody can really ignore them. Typical examples are the superconductors, new generations of composite materials, and new self - assembling materials.

Not all, but a large number of these materials are functional materials and, unlike most incremental or structural materials, they are either the result of scientific basic research and breakthroughs or of technology fusion efforts (see Chapter 3) which found their way to the market taking advantage of the most sophisticated S&P capabilities.

R&D on new materials has to start from the basic research stage and even earlier: from the fundamental physics and chemistry principles. Most of the new materials are the results of directed analytical R&D efforts and applications of theory prior to materialisation. Market size and returns are uncertain. As such, the R&D costs and risks from basic research up to commercialisation (and especially when no prior experience is involved) are massive. Returns, though, can be staggering[20]. New materials research is undertaken, despite the risks involved, due to the promise they hold to create new technologies and industries and control of these developments in the market place.

As a direct result very few grades of these materials (for the same application) exist. When a new material is successfully developed it is exploited up to its finest limit, and new materials usually dominate specialised markets and applications where cost is not always the first predominant parameter (and therefore the cost of long development periods can be compromised). They usually require a long-term perspective to be taken by industries and the time lag between applied R&D and

[20] Typical example is the case of the semiconductors, integrated circuits technologies and superconductors.

commercialisation is mostly uncertain[21]. Despite the cost and risk related disadvantages, NAM should be an important part of corporate or national material strategies. Under this scope, R&D in NM usually expresses the direction and nature of the technological and business **strategic vision** of the company.

The intermediates. Exceptions to the above distinctions are many and come mostly from materials which have been evolved to have dual intermediate character (both structural and functional) or are designed for very special applications. Optical fibers, a "bulk" application advanced functional - structural material with wide commercialisation opportunities, which was created and became feasible after dramatic S&P improvements in glass manufacturing, is a good example of the former and “smart” structural materials created for demanding applications in defence, aerospace or even construction are good examples of the latter. Dual character materials (structural materials with energetic response to stimuli such as smart materials and structures) are becoming more and more common and they require a combined R&D approach.

Overall remarks. Incremental or advanced materials (usually structural materials) contribute primarily to the redesign of the production process or product while at the same time strive to meet demand related and environmental requirements. They are related to rather widely available technologies exploited up to their limits.

New advanced materials (usually functional materials) determine the potential and availability of technical possibilities at a given time and to a large extent the development of a major field of existing or new technologies. They primarily depend on basic research and their development gives those who control them considerable influence over every related and relevant technology and business opportunity[22]. They are created to meet demanding performance requirements beyond limits of existing materials.

What is important is that the two main materials technological trajectories are **interrelated and complementary** to each other. Knowledge, capabilities and experience gained in one trajectory can be transferred effectively and used in the other because the MSE field is a unified, coherent field. An integrated MSE strategy calls for **simultaneous action on both** materials technological trajectories.

In fact, the strategy of improving existing materials when combined with the ability to tailor these materials for specific applications, is a short to medium term strategy. The

[21] For example, nobody can predict with accuracy when superconductors will find wide scale commercial applications.

[22] The 1995 DTI's Foresight Report on materials accepted that advanced structural materials rarely create new products but they can significantly improve existing products and retain competitiveness. New or advanced functional materials can create new products very rapidly. This distinction demonstrates that there are two major technological trajectories in the materials field and there by materials strategies.

creation of NAM which will be the basis for new technologies and markets combined with the increasingly acquired ability to build materials from the atomic level is a long term strategy, a strategy for the future retaining the possibility for a commercially exploitable breakthrough always active.

Incremental materials and advanced materials – mostly structural	**New materials and new advanced materials – mostly functional & intermediates**
Coming out of continuous evolution and improvement process	High potential of new properties and applications
They are the outcome of gradual S&P improvements, S&C control and structure - properties understanding	They are the outcome of scientific research and scientific breakthroughs
Offer the chance to traditional industries to be rejuvenated and diversify into new areas	Need to be structurally perfect
Require longer testing and commercialisation time	Require longer theoretical design times but they usually have shorter testing and commercialisation times
They are the first choice when entering the materials race because the supporting infrastructure for their development is widely available.	Developed and commercialised due to state of the art S&P
Lead existing technologies to their limits and prepare the ground for new technologies.	Revolutionise technologies and create new technologies – express strategic visions for the future.

Table 2.1: MSE and materials technological trajectories. (Source: Kottakis 1999)

In both approaches R&D focus, selection and direction[23] is crucial in order to avoid loss of time and capital[24]. This necessitates simultaneous design of materials, product and business strategies, continuous manufacturing process inputs and close producer - user collaboration and co-operation (see Chapter 4). That way, early mistakes during a product's or component's development can be avoided or eliminated. **Table 2.1** summarises most of the findings of sections 2.5. and 2.6.

2.7 Conclusions and recommendations

- The definition and classification issue in the MSE field is a serious one because apart from reasons of understanding and communication, it lies at the core of strategy choices offered by the MSE field. The employed working definitions are based on the "overall critical performance" criterion and on the recognition of the fact that the term "advanced" materials immediately refers to something improved with respect to the one it substitutes.

[23] For example, identify which materials show no room for further improvement and which materials are already covered by established large and strong international competitors and therefore provide little reason for investing in an already controlled and possibly saturated area.
[24] For example, Rolls -Royce spent considerable amount of capital and effort in developing MMC only to find out that these materials were unable to meet the specific applications they were intended for.

- Classification of materials depends on the purpose at hand and can be as accurate and precise as one would wish it to be. Classifications based on the materials nature of microscopic structure, on fundamental differences in the manner they are used and according to the level of sophistication and information intensity they include, are the most versatile classifications.

- The introduction of powerful computers, advanced instrumentation, and mathematical modelling techniques in the MSE field have ushered-in a Materials Revolution with most important characteristics, the ability to *tailor* materials after specific applications, the multi-disciplinary nature of the field, and the fact that materials *per se* emerge as high value-added products.

- What lies at the core of the MSE field and the MR, and what provides an underlying coherence to this diverse field, is the methodology for developing materials for useful applications. This methodology, regardless of materials class, has its origins in the four basic materials elements - Performance, Properties, Structure and Composition and Synthesis and Processing - and calls for a deep understanding of their nature, requirements and the relationships and interactions between them.

- Among the four elements of the MSE field the following relationships apply: Performance is the total sum of the synergistic action of the properties the material exhibits when stimulated in real working conditions, the measure of usefulness of a material in real working conditions and the connecting link of the MSE field with design, human needs and the market place.

- The properties of a material determine if the materials is attractive or potentially useful, and they directly originate from the material's structure and composition at all levels. But structure and composition is the result of specific synthesis and processing procedures. Synthesis and Processing capabilities are the connecting link of the MSE field with the manufacturing floor and *the basis of using* materials and materials technologies as *an enabling generic tool* in order to achieve both specific and multiple targets. The relationship between the four materials elements forms a close-fisted cycle (see also Figures 2.1 and 2.2.).

- Once a new target is set or a major scientific breakthrough occurs, the full power of MSE is needed to make something useful out of it. All the four basic elements of the materials tetrahedron must necessarily be involved if a successful result is to be achieved. Within this frame the *simultaneous* development of financially viable S&P techniques is crucial for successful commercialisation of any material aiming to serve volume applications.

- A set of inelastic factors originating and directly dictated by the nature of the materials tetrahedron and its scientific, engineering and technological requirements, is involved and affects all materials efforts -that is any materials strategy, regardless of materials class or type- at both corporate/industrial and national level. These common themes and considerations are listed in *section 2.4* and they place emphasis on balanced R&D activities covering all four materials elements, instrumentation, mathematical modelling and simulation skills, human resources issues, time horizon restrictions, synergistic and collaborative approaches, and supporting infrastructure issues.

- A major requirement is that materials strategies must be fully integrated with technology and business strategies (or national technology and industrial strategies at national level). This is because the MSE field is a coherent whole. If the early stages of developing and defining materials strategies (both at corporate and national level) are not drawn on the basis of the requirements of the four basic materials elements, these strategies will fail, leading technology (and business) strategies to equal failure.

- The implementation of structural and functional materials R&D activities includes and necessitates notable variations, but the basic R&D principles originating from the materials tetrahedron remain unchanged. However, R&D portfolio designers or materials and technology strategy designers must bear in mind that technical requirements and objective needs during the R&D implementation stages of different materials classes can vary considerably (see section 2.5). The argument gains crucial importance in the case where R&D and materials strategies are directly connected (or better tailored) to specific business objectives subjected to tight budgets or time-tables.

- There are two main technological trajectories in materials strategies: the strategy which aims to improve existing materials and optimise the way they are employed, and the strategy which aims to create new materials with new properties and functions and therefore create new products and possibly technologies. Structural materials usually belong to the first category while functional materials are mainly new materials.

- The two main materials technological trajectories are interrelated and complementary to each other. An integrated MSE strategy serves better business objectives when it keeps the balance and calls for simultaneous action on both materials technological trajectories.

CHAPTER 3: The Materials Revolution and Industrial Competitiveness

"All improvements in cost, quality and performance of product are materials related" (Daimler-Benz 1994).

"The company that controls materials development will dominate in the electronics industry." (Tadahiro Sekimoto, president of NEC)

3.0: Introduction

Chapter 3 addresses the issue of the materials revolution and industrial competitiveness within a general framework. It aims to provide evidence of the strong connection between materials and technological change, process and product innovations, emerging technologies, competitive advantage and business opportunities in the new global business environment.

In Section 3.1 the chapter identifies the basic characteristics of the new emerging business environment and argues that intensification of competition (on a global scale) is technologically based. In Sections 3.2 and 3.3 the chapter identifies the role of materials and MSE as a key element of technological change and as basic agents of process and product innovations. It argues that materials technologies are at the base of technological progress and innovation, that they directly affect manufacturing and processing technologies and organisational structures, and therefore they hold a central role in technology, product, and finally, business competitiveness.

Section 3.4 takes the argument one step further, providing evidence that most of today's emerging technologies are materials related or/and materials constrained. Section 3.5 provides some empirical evidence on the issue of materials and competitiveness by employing the findings of previous studies which explored and commented on MSE capabilities. In Section 3.6 the chapter identifies a set of business opportunities (e.g. diversification, technology fusion etc.) provided by the MSE field and argues that these opportunities can be achieved only if materials strategies are successfully integrated into technological and business strategies.

The chapter concludes with Section 3.7 which briefly identifies some necessary requirements an individual company must comply with in order to achieve successfully this integration and maximise its benefits. The identified issues formulate a number of parameters which shape the general framework of the second level of materials strategies (the corporate level).

3.1: The new business environment

The global industrial environment is in transition following rapid changes in market and competitive conditions. Since the early 1970s global developments have largely dismantled the 1950s ideas of production and organisation management[1].

Today, industry operates in a scientific, technology-intensive environment while the traditional producer-customer relationships have been completely modified. Moreover, new international players have entered the global arena. New high technology and knowledge-intensive industries or upgraded industries are at the root of globalisation acting both as enabling factors and as pressure towards further globalisation and competition intensification.

Simultaneously, customer behaviour has been modified. Customers have been "spoiled" by the abundance of new products and the variety of functions they have at their disposal. The new consumer is confident that his demands, no matter how extravagant, will be met by the manufacturers or services providers incorporating new and advanced technologies. The modern technological developments have given him this assurance. This adds extra pressure on global competitors intensified by fragmentation of demand up to the point of "individualism"[2] and by constantly rising cost reduction pressures.

As a result, globalisation of markets, faster product renewal, fragmentation of demand, customer-producer flexibility and variety at low cost, time based competition and real time agile manufacturing and delivery are some of the new business environment characteristics. **Table 3.1** summarises the main characteristics / challenges of the new business environment as it has evolved in the last two decades. Increasing technological and performance demands, product improvement pressures and life cycle demands are constantly placing higher performance requirements on materials inputs.

In order to meet the emerging challenges both manufacturing and services industries are restructuring in order to take on the opportunities offered by the generic and enabling technological revolutions of information technologies, materials technologies and, very recently, life sciences and biotechnologies.

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[1] These ideas were dominated by the Fordist mass production system which combined Ford's manufacturing and assembly line ideas with Taylor's ideas on scientific management and Sloan's ideas on managerial structures and controls.

[2] E.g. "I want my car royal blue, with ABS, no electric windows, special power arrangements, leather seats and delivered within a month..."

A NEW COMPETITIVE ENVIRONMENT	
TECHNOLOGY	• Basic scientific research underpins new technology development at several stages of the innovation process. • The pace of scientific and technological advance is accelerating. • The development and commercialisation of new technological innovations sustains competitive edge in the world market. • Concurrent R & D, product and manufacturing process tools facilitate in-built equality, meeting customer needs and shorter product life cycles. • Managing change. Creating change Vs responding to change central aspects of business strategy.
PRODUCT LIFE CYCLE	Shorter and continually decreasing product life cycles: • Globalization of production and intensification of world market competition. • Rapid technical change incorporated into more sophisticated, up to date, knowledge-intensive products. • Designer dominated or fashion orientated markets. • Evolving consumer lifestyles • Environmental concerns and slower demand may be leading to longer product life expectancy in the 1990s
PRODUCT IMPROVEMENT AND RENEWAL	• Continuous and rapid improvement in product and manufacturing process design, quality, productivity and cost. • Shorter product cycles and faster time to the market. • Rapid design changes.
FRAGMENTATION OF DEMAND AND GREATER VARIETY	• Disintegration and fragmentation of market demanding final and intermediate goods. • Need for small lot production, greater variety of productions aimed at specific market segments. • Sensitivity to individual requirement. • Trend towards mass customisation. • Diversification and product differentiation as strategic response to slower market growth. • Consumer resistance to endless modifications of existing products is now manifesting itself in several markets. • Lifestyle consumption as opposed to broad socio-economic group marketing. Global homogenisation of tastes, "World" products Vs local product designs.
VOLUME	• Market demand volatility. • Rapid output changes. • Economies of scope Vs economies of scale. • Smaller minimum efficient scale of plant.
PRICE	• Slower growth in demand. Market saturation in specific generations of products and regions. • Entry by low cost producers from the Far East employing people-orientated kaizen. • Ability to maintain or reduce price.
NON-PRICE FACTORS	• Innovative, aesthetically pleasing, functional design. • Incorporation of latest technology. • Fusion of complex, diverse technologies. • High and improving quality. • Environmentally compatible, recyclable, disposable products and industrial processes. • "Cradle to grave" materials life-cycle considerations.

Table 3.1 continued

CUSTOMERS	• Getting close to customers. Fast market response. • Anticipation of evolving needs. • Listening to most technologically sophisticated and demanding customers to feed back into frontier R & D. • Faster product order scheduling and delivery. • Before – during – after sales services.
SUPPLIERS	• Collaborative Vs adversarial relationships. • Physical proximity, JIT delivery, quality, logistics of delivering heavy near net shape components and sub-assemblies. • Continuous improvement. Early supplier participation in simultaneous engineering. • R & D collaboration in materials, components and final product design and production. • In-house Vs external sub-contracting of core materials and components.
MATERIALS	• New technologies in several industries are placing higher performance requirements on material inputs. • Proliferation of new polymers, metals, ceramics and composite materials. • Increasing ability to design/tailor materials to specific applications. • New adhesives and joining technologies. Near net shape processing technologies. • Redesign of product and process using new materials displaying greatly enhanced properties and performance characteristics. • In-house Vs external materials R&D sources.

Table 3.1: The new Business Environment (Source: Kaounides 1995d)

Materials technologies for example, can provide the opportunity to turn the fragmentation of demand challenge into a competitive advantage: given that materials can be tailored to specific applications, they are increasingly integrated into the process of designing new products or services. This gives firms the ability to differentiate their basic product models -or even a set of different basic models- in order to satisfy the fragmented demand. But, to achieve that, they must have already installed a flexible and adaptable manufacturing system which simultaneously has to be cost and quality effective.

Shorter product life cycle can also become an advantage: materials today can be tailored to have specific performance life-time before they fail and components made from these materials have equally accurate life cycles. It is the decision of the manufacturer as to how short or long a product's life-cycle will be.

It follows that the intensification of competition is technologically based. The following sections argue that many aspects of technology and technological advancement are materials constrained. Therefore, industrial (and hence economic) competitiveness is in many cases materials constrained.

3.2: Technological change and Materials Science and Engineering: Technology and process/product innovation in industry

The following sections identify the role of materials and MSE as key elements of technological change and as basic agents of process and product innovations. They argue that both in the past and in modern times, materials technologies are at the base of technological progress and innovation, while they directly affect manufacturing and processing technologies and organisational structures and therefore they hold a key role in technology, product, and finally, business competitiveness.

3.2.1 Materials and man: A brief historic review

The intentional activity of giving new properties to materials by altering their structure, properties and performance called today Synthesis and Processing, is as old as human history. For example, clay (from which pottery and *kilns* are made) is considered to be the first inorganic material to be given new properties as a result of an intentional activity. Kiln technology is the first step to extract metals from ores and give pure metals new properties and abilities. Similarly, skilfully worked stone tools and, later, much superior metal-based tools greatly increased the productivity of agriculture, providing a continuous stream and surplus of food which could support large numbers of population in a permanent location.

Much later, the continuous improvement in the standards of living, life expectancy, knowledge accumulation on science, engineering and materials technologies gave birth to the industrial revolution (1780s) based on iron and coal and then steel (1860s), as the key materials. Steel led to dramatic technological improvements but brought forward a new issue: for the first time energy sources and energy production, utilisation and distribution as well as effective energy exploitation became important. The need for energy led to the use of oil and the invention of electricity.

In modern times, the introduction of advanced modelling and simulation techniques and advanced instrumentation and computer power into the empirical materials field created a real materials revolution which in turn revolutionised mechanical design and processing and all related technological fields, including instrumentation technologies and computer technologies.

This brief historic review demonstrates that a civilisation's level of development and technological sophistication is limited by the amount and type of the materials at its disposal and especially from the level of knowledge intensity employed to alter the properties of the materials used, that is, S&P capabilities. Man was, is and will be dependent on the materials world surrounding him and on his abilities to alter and transform it for his own good (Drexler 1992).

3.2.2: Technological innovation and Materials Science and Engineering

As seen in chapter 2 the MSE field is immense and diverse. But the role of materials in technological and "product" change and the innovation process is not widely acknowledged (Kranzberg and Smith 1988) because materials have not a "directly visible" influence on technological change. What is really important is what they and their related technologies can do and facilitate in products, technologies and process development and not their individual value *per se*.

Impact on technologies. First of all, materials (and hence materials technologies) are strongly connected to technological and product change because all physical products and processes are materials related. There is almost no physical or technical mathematical formula or law of nature where the natural or physical properties and magnitudes of materials do not have a strong part and influence on the outcome.

As such, materials have a crucial impact on established and emerging technologies (see also section 3.4). As three leading US agencies (DOD 1990, DOC 1990, NRC 1989) pointed out, AM and their commercial or military applications will facilitate solutions to pressing medical, energy, transport, construction, telecommunications, information technologies and environmental problems[3].

Impact on products. As in technologies, materials have an equally dramatic impact on products and components which in turn initiate further change in both technologies and markets. **Annex 3.1** summarises some striking examples of recent progress in materials and just a few of their commercial applications and impacts on "products", services and technologies.

Impact on tools. Development of new machinery and instrumentation which in turn promotes technological change makes heavy use of materials achievements. In

[3] For example, materials and IT have a closed-cycle relationship: progress in materials technologies depends on further progress in IT while IT is strongly materials constrained. Due to the advances in computer power and materials all other technologies continue to benefit. Flexible manufacturing systems (FMS), CNC machines, automation, robotics, the entire field of analysis and modelling would not be achieved without the materials or the materials production lines upon which computer technologies are based. Conversely, these developments would not have been achieved without advances in computer technologies.

return, updated machine and equipment components are essential to improve S&P capabilities of any industry - notable examples are semiconductor processing equipment - and the abilities of any research institution or laboratory (e.g. new electronic microscopes) to open ways to new scientific and technological frontiers. In addition, sophisticated machinery and experience obtained during materials development can be diffused to other areas, providing the opportunity for new products and services to appear. And the cycle goes on. But due to high development cost, and due to its indirect and "hidden" role in influencing technological change, this point, and the role of materials with it, is frequently overlooked.

3.2.3: Materials Science and Engineering and the manufacturing process

What differentiates a "traditional", labour-intensive industry and the 'intermediate' assembly industries from a technology intensive industry is the very limited participation of raw materials cost in the final product value. A high technology product's additional value is nothing else than the know-how value required for its production / manufacturing (Kranzberg and Smith 1988). In turn, manufacturing and production processes practically absorb and combine existing technologies and know-how to produce products and deliver services.

Throughout industrial history, various trades and industries have grown up in connection with the *processing* of a specific group of material(s). A wide range of subjects (such as machinery, organisational structures, training courses and systems, management practices and the accumulation of experience) have been inextricably linked with the processing of specific materials or groups of materials. Therefore, a technological shift based on *new* materials introduction would involve the re-design of the 'product' and its entire manufacturing process which in turn affects directly and indirectly the manufacturing, organisational and industrial base, inventory and machinery, suppliers and customers relationships etc. Hence, the introduction of radical materials innovations is feasible only over a medium to long term process.

On the other hand, a shift within similar groups or advanced forms of existing materials need not entail significant changes because it incorporates existing experience and does not necessitate immediate drastic changes on the factory floor, of peoples' education or the infrastructure of the firm or industry. Involved cost and risks are also smaller.

Thus, new materials usually do not substitute directly and immediately old materials (Hansen and Serin 1994, Madsen 1991). This substitution is gradual and passes through many incremental stages and levels.

According to the above, when competition pressure necessitates the employment of a new material for a specific product there are two ways of action: either employ a new group of material and change the manufacturing line or develop a new or an advanced material which but can be worked with the existing manufacturing line, though probably requiring new tools and process adjustments (e.g. high-strength steels and advanced aluminium alloys in the car industry replace conventional steels).

Change from one class of materials to another (e.g. from metals to ceramics) is the most demanding and risky and requires considerable capital and time. Change from one grade of a specific group of materials to another advanced grade of the same group (e.g. Al-Li alloys for conventional aluminium) is considered faster, cheaper and safer.

Finally there is an intermediate case: changing not the class of materials but the group of materials. The change from ferrous to non-ferrous metals is a typical diversification example. Experience working with metals family (A) can be used for metals family (B). The shift from steel to all-aluminium car body example from Audi is a typical example of the case (see also Section 4.3). This type of change still involves high risks and requires considerable amount of time and capital (e.g. seven years of collaborative R&D by Audi and Alcoa to achieve the shift in Audi aluminium frame cars) but is more radical than the second case while less risky and expensive than the first case.

3.2.4: Changes in the characteristics of materials production

Section 3.2.3 analysed the impact of materials on technological innovation and the manufacturing process. Furthermore, the relationships among technological innovation, the manufacturing process of both materials *per se* and components and the MSE field are reciprocal and in many cases, complementary.

MSE strengths combined with Information Technology skills and advanced manufacturing capabilities (e.g. numerical control of the manufacturing process, CAD/CAM, CNC machines etc.) and the appropriate management tools and strategies[4] do not only revolutionise products and processes but they also introduce

[4] Namely Kaizen, Lean Production and Simultaneous Engineering practices presented in chapter 4.

considerable changes in the *characteristics* of the materials production *pe se*. The most important of these changes are summarised with **Table 3.2**.

Conventional material style	Advanced materials style
Control over the macrostructure of matter	Control over the microstructure of matter
Relative division between research, design, production and application of materials	Increasing integration of these activities
Large markets with low or even negative rate of consumption growth	Relatively smaller markets with faster rate of growth
Low-cost standardised commodities produced in factories geared to increasing scale-conditioned efficiency and used in a large number of products	Larger variety of tailor-made materials with integrated function, high purity, higher value added and better compliance with environmental regulation
Major consumers: transportation and construction sectors	Major consumer: information and telecommunications sector
Raw-materials and energy-intensive	Information-intensive
Specialised skills	Multidisciplinary team-work
Dedicated plant and equipment	Multi materials plant and flexible production systems
Automation	Computerised intra and inter firm links
Low R & D expenditure	Very high R & D investment.
Predominance of process optimisation and other incremental innovations	Importance of basic research and of research on specific market applications
Predominance of internal sources of technology (engineering and R& D depts)and of suppliers of specialised inputs	Importance of networks of research, production and application of AM. Consumer sectors as important sources of new technologies
Statistical testing, usually destructive and conducted outside the production process	Predominance of non-destructive testing conducted simultaneously with the production process
Big single firms and cartels dominating research, production and consumption	Predominance of specialised divisions of big and small and medium size firms. Intense collaboration at national and international levels
Sources of raw materials and energy influencing firm behaviour (e.g. location of production, integration, etc	Importance of the access to specific markets and to sources of technological expertise influencing firm behaviour
Importance of backwards integration. Material producers tending to control sources of raw materials	Vertical and horizontal interactions. Material users tending to become producers and material producers tending to become users.

Table 3.2: Changes in the characteristics of materials production. (Source: Lastres 1994)

Simultaneously, these changes introduce a major restructuring of the basic materials industries (materials producers and suppliers). The most important shifts of this transformation (as developed by Kaounides (1994a)) are:

- From commodity production to higher value-added specialities.
- Acquisition of multi-disciplinary and multi-materials competencies. Offering a full or wider product portfolio.
- Vertical integration and diversification into new and advanced materials.
- Economies of scope in production, product differentiation with respect to performance and niche marketing.

- Continuous improvement, supplier partnerships, getting close to customers and adapting customer and collaboration-oriented and continuous improvement management techniques.
- Creating the ability to offer "materials systems" to final users and enter into joint R&D alliances with other producers or users or both.

The changes in the materials production characteristics, the opportunities offered by the MR and the new characteristics of the basic materials industries, become the departure point for the development and efficient support of aggressive materials-based business strategies such as materials related rejuvenation, diversification and technology fusion strategies (see section 3.6: materials and business strategies).

3.3: Materials and the Innovation Process

The previous sections demonstrated the strong inter-connection between materials and technological change. The aim of this section is to investigate the connection between materials development and evolution and the innovation process. The section argues that change and evolution in materials and their implementations provide striking examples in terms of understanding innovation and the innovation process while verifying existing, well established innovation theories.

The innovation process. According to Mort (1994), innovation, strictly speaking an economic parameter and quite distinct from the important factor of invention, involves the profitable marketing of a new product or service (commercialisation). There are also sub-divisions of innovation that can be usefully made. First are the rare, radical innovations which create markets (e.g. breakthroughs - new technologies - new materials - advanced S&P methods), second are the more common radical improvement innovations which significantly influence existing markets (e.g. advanced structural steels, liquid crystal displays for flat screens, radically improved materials or processes) and, finally, what have been termed "pseudo-innovations" which produce barely differentiable changes in extant markets (small and slow, but with cumulative effect, incremental improvements in materials or processing methods).

Furthermore, the OECD report on Technology and the Economy (OECD 1989), Schumpeter (1939 and 1942), Mowery & Rosenberg (1989), Pavitt (1971 and 1996a), Freeman (1991), Porter (1990a), have argued that the innovation process is **not** a linear process of successive distinct stages as the one presented in the linear model of innovation (see top of **Figure 3.1).** It is a complex process defined by a complex system of constantly interacting factors and parameters[5]. This complex process seen in **Figure 3.1** is a combination of both incremental and rapid / radical changes and contains considerable amount of "feedback" and overlaps. According to the non-linear model of innovation, all three sub-divisions of innovation are both interconnected and strongly and reciprocally connected to their environment.

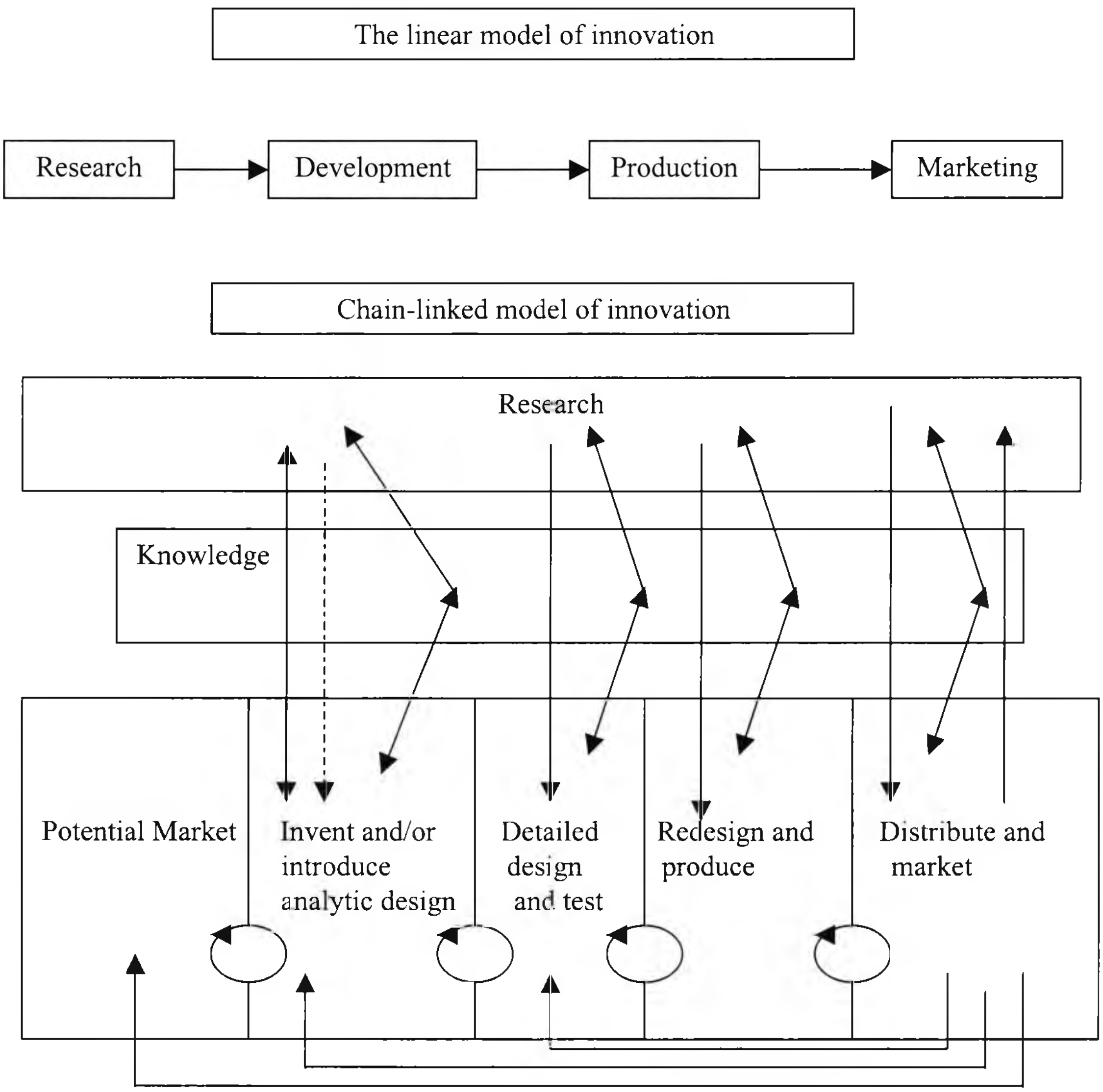


Figure 3.1: Models of Innovation. (Source: Kline and Rosenberg 1986).

Materials and the innovation process. By combining these concepts with sources such as the works of Kranzberg and Smith (1988), Cohen (1979), Commoner (1971), Lilley (1966), Lastres (1994) and Kingery (1990) on the role of materials in

[5] As Pavitt (1971) suggests with respect to technological innovation, major scientific breakthroughs do not occur at regular intervals, while incremental innovations which can be a potential source of steady revenues and profits should not be neglected.

technological and social change and innovation, the following conclusions can be derived:

I) Materials evolution and innovations could not be better illustrations of the above concepts. First of all, the materials case clearly demonstrates the difference between innovation and invention: there is no value in inventing a material without integrating it into an application. Secondly, the three sub-divisions of innovation find excellent application in materials developments. Innovations with revolutionary impact such as high temperature superconductors are rare. Major improvements or inventions of new, more effective, S&P techniques (e.g. rapid solidification), a second type of innovations which significantly influence existing markets, are more frequent and, finally, the constant, incremental, improvements in materials properties and performance or "spot" improvements in S&P (e.g. the introduction of a better sensor) can be classified under the pseudo-innovation division.

II) Technological change and innovation in materials occurs either when a totally new material with superior properties, (advanced material), is employed, or when a slow but continuous or even drastic improvement of materials employed occurs, producing higher grades of materials with superior properties (i.e. from crude stone to elaborate stone and from iron to steel).

III) Even when the discovery and employment of a new material is considered to be a breakthrough it is not just the single material that makes the change but *a supporting network of activities* around this material (i.e. instrumentation, specific needs and supporting activities) as well the products this material makes possible. As emphasised by Schumpeter (1939), successful innovations *do not remain isolated events* but on the contrary *they tend to cluster.*

IV) The transition process from one stage to the next in materials development and substitution can be revolutionary in impact but relatively slow in terms of time scale.

Changes in materials innovation and application within the last half century, however, are occurring with exponential rates in a time span which is much more revolutionary than evolutionary[6] while the impact they have on their "environment" still remains revolutionary.

V) When an improved or totally new material enters the market it starts a new technological cycle or it becomes a part of a technological cycle leading to new developments and further change. The overall materials evolution procedure over time

[6] The adaptation of a new material and its employment in a final product could take from thousands to dozens of years; today the average time gap tends to be from 15 years to considerably less than a decade.

is a continuous procedure, while the changes inflicted on the materials "environment" tend to be discontinuous and rapid, and the disruption caused by the change often creates opportunities for new competitive advantage or social and economic progress (Ashby 1987). As such, materials changes and their impact on numerous technological fields and hence business and social environment make a fine example of *"creative destruction"*, (Schumpeter 1942), and of a non-linear, dynamic innovation process.

VI) Modern innovation in materials is the result of a *combination* of both evolutionary and revolutionary process. These two tendencies *are complementary - not antagonistic* - to each other. Therefore, the materials and materials technologies evolution and development is a continuous, incremental process which advances either by smooth continuous small changes with accumulating effect, or by sudden rapid advances which take place only when the necessary conditions reach an appropriate "critical mass" of synergistic action. This *combined action* explains why there is no antithesis in the way different classes of materials evolve, change, or become obsolete.

VII) In some industrial fields (e.g. information technologies and aerospace) performance requirements escalate continuously with accelerating rates necessitating the constant introduction of new advanced materials in these fields. On the contrary, performance demands in other fields such as construction are increasing with a relatively slow pace. As such, the introduction of new materials to these fields is much more limited. The reasons "old" materials are still employed is because they are either needed in immense, bulk quantities or because they still do the job they are supposed to do effectively and at low cost, or because they can be considerably improved, thereby employing the experience accumulated during their long history of employment. Acceptable performance and / or properties, gained experience, and / or economic or political reasons (e.g. standards) are the main drawbacks for materials innovations.

3.3.1: Materials innovation and the market-pull / technology-push (MPTP) debate

Chidamber and Kon (1994), after an extensive review of studies covering both views of the MPTP debate, concluded that although the researchers on the two sides of the MPTP debate disagree as to their respective positions, there exists a unifying framework which allows both results to coexist. It may be indeed true that the majority of commercially successful innovations are market dependent or immediately inspired by market information (e.g. the developments in steel and steel production) but this does not show that they were not founded upon some existing scientific base of knowledge. If this were the case, as suggested by Casey (1976), then both the science and the market forces would be critical *in complementary fashion.* On the other hand, technology push innovations are fewer in number but they may fuel a larger number of incremental innovations or spill-over effects (e.g. semiconductors and the information technologies).

This is exactly the materials case: most materials developments (e.g. incremental materials) are based upon demand-pull but there are many examples (e.g. semi-conductors and recently super conductors) which have created new markets and technologies. The author suggests that with respect to materials technologies the MPTP action is becoming increasingly inseparable[7].

In addition, Morita (1992), chairman of the board of Sony Corporation, while attacking the linear innovation model, identified that corporate and even national competitiveness depends not only on scientific and technological skills but also on the ability to commercialise R&D and materials technologies successfully. Given that almost always materials are integrated into more complex components and systems, S&P, manufacturing and commercialisation skills should also be in place for successful (and profitable) innovation (Morita 1992, The Innovation Agenda, DTI 1994).

To summarise the preceding arguments, MSE related innovations effect technological change and thereby technology and competitiveness both in terms of final products, components (and occasionally services) and in terms of improved or radically changed production / manufacturing process.

A shift in materials technologies will not only influence the individual company but it will also radically influence industrial structure in general, the transfer and use of knowledge and the type of relationships between firms and industries. It is a long process but it is also a necessary one if companies or industrial sectors expect to compete successfully in modern competitive conditions.

[7] Optical fibers is a very good example: their development was market motivated. The demand for better and more complex communications is constantly rising. But since fiber optics were invented they have generated an entire new group of optoelectronic technologies which can ultimately lead to the creation of the fully photonic computer.

3.4: Materials Science and Engineering and Emerging Technologies

According to US Department of Commerce (DOC) emerging technologies are broadly defined as follows:

> "Emerging technology is one in which research has progressed far enough to indicate a high probability of technical success for new products and applications that might have substantial markets within approximately 10 years."

As such, emerging technologies must be viewed as having the potential to either create new products and industries with markets of substantial size and/or provide large advantages in productivity or in the quality of products produced by existing industries which supply large important markets. This is achieved by either making a direct technological impact or by advancing the quality and efficiency of technological infrastructure and the manufacturing process. Leadership in an emerging technology provides more than a head-start in developing or commercialising successive generations of breakthroughs in a given technology or other related technologies.

Materials and Sensor Technologies. Sensors are devices that provide a signal (generally optical, magnetic, electrical, or acoustical) that accurately reflects some process parameters in real time. Advanced manufacturing and continuous processing, intelligent systems and robotics (environment recognition) and monitoring technologies heavily depend on sensor technologies. Automatic control theory, industrial engineering and electronics are still a restriction but sensor technologies are mainly materials-restricted as most of the sensors employed are a special group of materials called smart or intelligent materials. Most modern sensors are made of new metals, piezoelectric and magnetic or optical materials. Currently, sensors lack one or more of the following characteristics: range, stability precision, resistance to harsh environments, selectivity and sensitivity. Most of these limitations are materials related. Progress in the field is noted by new sensors which can measure parameters more accurately and in real time under a wider range of conditions due largely to better materials, fabrication techniques (synthesis & processing) and more complex electronics and data processing.

BOX 3.1: Materials and sensor technologies. (Source: Author and various sources).

MSE and Emerging Technologies. The central role of AM technologies as both emerging and enabling technologies is reaffirmed by every major study on critical or emerging technologies world-wide (e.g. the UK's DTI 1995 and the US DOD 1990, DOC 1990, and NRC 1989 studies). In these reports AM technologies are listed as both top priority emerging technologies and as enabling technologies upon which (together with the IT technologies) nearly all other emerging technologies have to rely. The argument is demonstrated by **Table 3.3** and by two illustration examples provided with **Box 3.1** and **Box 3.2.**

Materials and Information Technologies (IT). Information Technologies is a very good demonstration because it has been well established what potential these technologies have in flexible manufacturing systems (FMS), CNC machines, automation, telecommunications, robotics, the entire field of analysis and modelling, services and numerous others. What is not widely known and appreciated, though, is that information technologies are strongly materials related or materials constrained (Kaounides 1995d – see also Annex 2.3).

To begin with, IT would not be a reality as known today if the Silicon and Ga-As semiconductors, magnetic, and recently, optical materials, and reliable, defect free, manufacturing process of these materials were not employed, generating a stream of entire new technologies. Computer effectiveness and efficiency is based upon hardware characteristics such as computational speed, results reliability, and memory (data storage) capacity and upon software (programmes and "language").

Much of hardware achievements is the result of a fusion between electrical / electronic architecture and design and materials technologies. Hardware, apart from electronic architecture and physics heavily relies on progress made on semiconductors and micro-processors and on memory storage materials:

- Advanced semiconductor devices and microprocessors (on which speed and efficiency critically depends) incorporate the improvement and development of *materials*, their fabrication techniques and advanced components and devices for use in electronic and computing equipment of all kinds. Computer performance heavily depends on these improvements.
- High-density data storage involves the development or improvement of erasable data storage devices offering several orders of magnitude improvement in information storage density. It also incorporates the improvement and development of *materials*, their fabrication techniques and advanced components and devices integrated to the operational system.

Solid state physics and band theory provide the theoretical basis for the principles upon which IT technologies are based, but the development of real applicable products came only when theoretical knowledge was coupled with materials science and engineering.

For example, the multi-media industry is based upon the purification of silicon or other semiconductor materials, the laser processed and accessed materials from which CD / ROM disks are made and especially optical fibers (also see Annex 2.3: Information Technologies).

For semiconductor devices in particular, Gerard Matheron (Matheron 1992) of SGS-Thomson predicts that the semiconductor chip's progression to infinitesimally small engravings will reach 0.2 microns by the year 2000 and 0.07 microns by 2010. As a result processor speed for cheap domestic computers will reach 1000 Mhz compared with 300 Mhz today. Dram memory will also increase dramatically: according to the American Semiconductor Industry Association (SIA), this should double in density every 2-3 years reaching 64Gbits in 2010.

At 0.07 microns the semiconductor chip will reach its optimum functional capacity as semiconductor. New materials such as polymers or optical materials taking advantage of the quantum effect or substituting electrons with light will be needed to be developed.

In conclusion, materials technologies enable the creation of powerful computers. As NEC president Tadahiro Sekimoto put it: "*The company that controls materials development will dominate in the electronics industry.*" These computers assist considerably in promoting materials understanding because materials and IT find common ground in advanced instrumentation, modelling, simulation and advanced measuring and testing techniques.

IT and materials technologies are entirely interconnected. Progress in any of them has a direct impact on the other and vice versa. Together, they account for the two major generic and enabling groups of technologies upon which progress in any technological field critically depends.

BOX 3.2: Materials and Information Technologies. (Source: Author from various sources).

Table 3.3 provides a comparison of emerging technologies as identified by the US DOD (**right column**), the US DOC in 1990 (**central column**) and the National Critical Technologies Panel (**left column**).

NATIONAL CRITICAL TECHNOLOGIES	COMMERCE EMERGING TECHNOLOGIES[1]	DEFENSE CRITICAL TECHNOLOGIES[2]
MATERIALS ● Msterials synthesis and processing ● Electronic and photonic materials ● Ceramics ● Composites ● High-performance metals and alloys	● Advanced materials ● Advanced semiconductor devices ● Superconductors } Advanced materials	● Composite materials ● Semiconductor materials and microelectronic circuits ● Surperconductors } Composite materials
MANUFACTURING ● Flexible computer integrated manufacturing ● Intelligent processing equipment ● Mico- and nanofabrication ● Systems management technologies	● Flexible computer integrated manufacturing ● Artificial intelligence	● Machine intelligence and robotics
INFORMATION AND COMMUNICATIONS ● Software ● Microelectronics and optoelectronics ● High-performance computing and networking ● High-definition imaging and Displays ● Sensors and signal processing ● Data storage and peripherals ● Computer simulation and modelling	● High-performance computing ● Advanced semiconductor devices ● Optoelectronics ● High-performance computing ● Digital imaging ● Sensor technology ● High-density data storage ● High-performance computing	● Software productivity ● Semiconductor materials and microelectronic circuits ● Photonics ● Parallel computer architectures ● Data fusion ● Data fusion ● Signal processing ● Passive sensors ● Sensitive radars ● Machine Intelligence and robotics ● Photonics ● Simulation and modelling ● Computational fluid dynamics.
BIOTECHNOLOGY AND LIFE SECIENCE ● Applied molecular biology ● Medical technology	● Biotechnology ● Medical devices and diagnostics	● Biotechnology materials and processes
AERONAUTICS AND SURFACE ● Aeronautics ● Surface transportation technologies		● Biotechnology materials and process
ENERGY AND ENVIRONMENT ● Energy technologies ● Pollution minimisation, remediation, and waste management		
		● No National Critical Technologies counterpart: High energy density materials, Hypervelocity projectiles, Pulsed power, Signature control, Weapon system environment.

Table 3.3: Comparison of national critical technologies with commerce emerging technologies and critical defense emerging technologies. (Source: US DOD 1990, US DOC 1990).

[1] U.S. Department of Commerce, Emerging Technologies: A Survey of Technical and Economic Opportunities. Spring 1990

[2] U.S. Department of Defense. Critical Technologies Plan. 15 March 1990.

The National Critical Technologies Panel (NCTP) study[8], selected 22 technologies deemed critical for military and economic competitiveness which required concentrated effort. From the 22 technologies identified, five are materials technologies, while five others refer directly to processing and manufacturing technologies. This report follows the line of the 1989 NRC report putting special emphasis on the need for US industry to adapt an integrated, incremental, continuous improvement approach to both product development and associated manufacturing processes - that is S&P capabilities and technologies. The report also calls for attention to manufacturing and product development issues associated with the other 12 critical technologies.

In Spring 1990 the US DOC published a study on the competitiveness of the US technology under the title: '*Emerging technologies: A survey of technical and economic opportunities*'. The purpose of this report was to provide a source of information to be used by industry, government and academia as programs and policies were developed to exploit new emerging technologies. The report identified 12 emerging technologies, (listed at the middle column of Table 3.3) with a total annual potential market turnover of $356 billion product sales by the year 2000, and indicated that if current (1990) trends continue, before the year 2000, the US would lag behind Japan in most emerging technologies and will trail EU in several of them. Three out of the 12 crucial technologies considered were pure materials technologies and in most of the others the materials were again the enabling factor. Economically the most important of the 12 identified technologies are the "Advanced Materials" field for which US annual sales of $150 billion were forecast and the sector semiconductors with $75 billion sales for the year 2000. The direct aggregate of the three materials technologies comes to $230 billion potential annual sales. The indirect aggregate is expected to be much higher.

In tune with the findings of the US DOC, in a 1990 study, the critical defence technologies were examined by the US-DOD and 20 technologies were identified out of which five were pure materials technologies (Table 3.3 right column).

All three reports identified that materials technologies appear to be predominant priorities and on the forefront of the technological portfolio of Japan and the EU.

Indeed, on the other side of the Atlantic, the EU has dedicated one of the largest R&D initiatives to materials, manufacturing and industrial technologies (the Brite-Euram programs). These programmes (examined in detail in chapter 10) are dedicated

[8] Report of the NCTP, Washington, January 1991.

to industrial, scientific and technological activities directly or indirectly related to materials technologies.

Finally, Japan was the first country (in the early 1980s) to officially identify AM technologies (termed New Materials in Japan) as both emerging and enabling technologies. For example, in an early but long-range technological forecast study[9] carried out by the Japanese Science and Technology Agency 15 fields of science and technology were evaluated, ranging from education, environmental matters, and health to microelectronics. Most of the technology categories in this forecast rely directly or indirectly on materials developments (see the asterisk marked items). Other and more recent Japanese reports (e.g. the JETRO report in 1991, The Japanese White Papers on Science and technology 1994/96) invariably identify materials technologies as first priorities of crucial strategic and economic importance.

In brief, all the above reports highlight the importance of AM technologies as emerging technologies *per se* and as enabling technologies for further technological progress and clearly call for *portfolio investment policies* in both materials and other emerging technologies by arguing that breakthroughs cannot accurately be predicted, but when they occur they have a major impact on all related technologies and economic activities.

3.5: Materials Science and Engineering and competitive advantage: some empirical evidence

The previous sections underlined that the MSE field has emerged as a coherent field upon which further progress in technological innovation and competitive advantage depends while chapter 2 argued how crucial it is to build any materials effort according to some basic guidelines directly derived from the nature of the MSE field and the materials tetrahedron.

The relationship between materials strategies designed according to these lines, and their connection to corporate and industrial competitiveness was thoroughly investigated by the US NRC (1989) committee on Advanced Materials and published in the NRC under the title '*Materials Science and Engineering for the 1990's: maintaining competitiveness in the age of materials*'. According to the NRC path-

[9] " Technology Development Forecast up to 2010 in Japan " , Science and Technology in Japan , 1983.

breaking report[10], during the 1970-1988 period some of the American basic industries[11] have suffered severe losses of their market share on both national and international ground contributing significantly to the increase of the national balance of payments deficit. Moreover, large sectors of the American economy and industry became more vulnerable to competition originating from once inferior international competitors mostly located in the Far East.

The US NRC committee investigated eight industries considered critical and crucial for the US national economy, commerce and defence. These include sectors such as defence, space, energy, transportation, biotechnology, telecommunications and every day products (such as consumer chemicals, commodity metals etc.). **Table 3.4** provides the economic impact of the eight industries. **Table 3.5** provides the international trade balance for selected industries and reflects the recent performance variations and **Table 3.6** provides the basic materials needs for the eight industries. **Table 3.5** suggests that the eight industries can be classified into the following categories (according to the NRC study the biotechnology-biomaterials industry has been omitted from the table due to its relatively small size and its dependence on the chemical industry in terms of trend sin the 1980s):

- Industries losing ground badly with accelerating or stable rates: automotive and metals,
- Industries losing ground with accelerating rates: telecommunications and electronics,
- Industries losing badly with retarding rates: energy,
- Industries gaining ground with stable or accelerating rates: aerospace, chemical and biotechnology-biomaterials.

It is not a coincidence that industries in worst position were identified to be the traditional automotive, metals and energy industries whereas the most successful are those which include or are based on high technology and innovating management attitudes (aerospace, biomaterials, chemicals). Most of these industries are highly interactive and interrelated (e.g. the automotive with the metals industries; the chemical and biomaterials industries).

Among others, the NRC committee underlined the finding / conclusion that MSE capabilities and competitive positions are closely interrelated. The sustainability / strength or erosion of domestic MSE capabilities - S&P and commercially oriented

[10] This valuable report reflects tendencies and trends in the late 1980's. Its recommendations and findings had a significant role in re-shaping the US attitude towards materials technologies (see also Chapter 4).

[11] Basic industries: heavy manufacturing industries such as steel, automotive, aircraft, chemicals, machinery, rubber, glass.

R&D capabilities in particular - at both national and industrial level, and their integration or not to modern technologies and management philosophies, was one of the main reasons behind the deterioration or the growth of these industries.

Industry	1987 Employment[a] (thousands)	1987 Sales ($billion)
Aerospace	835	105.6
Automotive	963	222.7
Biomaterials	-	>50
Chemicals	1004	195.2
Electronics	1394	155.4
Energy	1229	375.8
Metals	629 (1230)[b]	98.9
Telecommunications	1007	146.0

Table 3.4: Economic impact of the Eight US industries. Source: US NRC 1989.

[a] The statistics are taken from the U.S. Industrial Outlook 1989, published by the Department of Commerce, International Trade Administration, Washington, D.C.

[b] The 1980 to 1985 average based on a broader definition of the metals and mining industry used in Employment Prospects for 1995, Bulletin 2197 published by the Bureau of Labor Statistics, Washington, D.C. (1984)

Industries	**1982**	**1984**	**1985**	**1986**	**1987**
Aerospace	+11.1	-10.2	+12.3	+11.7	+15.1
Automotive	-10.4	-20.7	-26.5	-35.8	-42.4
Chemicals	+12.4	+10.7	+8.5	+8.5	+9.3
Electronics	+6.7	+2.5	-2.6	+0.6	-0.1
Energy	-53.3	-52.7	-44.2	-30.8	-38.3
Metals	-9.5	-12.9	-11.6	-9.6	-10.8
Telecommunications	+0.2	-1.0	-1.2	-1.3	-1.7

Table 3.5: International trade balances for seven selected US industries (billions of dollars) Source: US NRC 1989.

Desired Characteristic / Industry	Aero	Auto	Bio	Chem	Elec	Energy	Metals	Telecom
Light/strong	X	X	X					
High temperature Resistance	X			X		X	X	
Corrosion resistance	X	X	X	X	X	X	X	
Rapid switching					X	X		X
Efficient processing	X	X	X	X	X		X	X
Near-net-shape forming	X	X	X	X		X	X	
Material recycling	X	X	X	X	X		X	
Prediction of service life	X	X	X	X	X	X	X	X
Prediction of physical properties	X	X	X	X	X	X	X	X
Materials data bases	X	X	X	X	X	X	X	X

Table 3.6: Materials needs of the Eight US industries Source: US NRC 1989.

Industries with a high degree of material strategies integration into their domestic industrial, technological and manufacturing infrastructure were found to be doing well or retaining position, whereas others not following or adapting MSE strategies along these lines were falling behind and are losing competitive position.

Finally, **Table 3.6** reflects the committee's finding that many materials needs, and subsequently the associated strategies, are common for many industries. A homogeneous approach can be applied from which many industrial sectors can benefit. This point also assists the private sector to realise that they had much to share and benefit *from a co-operation* on basic common problems.

3.6: Materials and Business Strategies

Given that materials technologies and capabilities are crucial factors for technological change and industrial competitiveness, they have a strong influence on business policies and executive decisions. Having secured strong materials capabilities, (with S&P capabilities in particular[12]), as a departure point for product, process and service innovations, corporations can respond to competition intensification by moving forward with the following strategic options: **rejuvenation, diversification or technology fusion strategies**.

These three strategic choices are interrelated as **Figure 3.2** suggests, with materials capabilities acting simultaneously as both the departure and the connecting point:

- Rejuvenation strategies based on materials capabilities are usually the first strategic response to competition intensification and can provide the origins of diversification and technology fusion strategies.
- Diversification strategies can lead to corporate / firm rejuvenation and accelerate or become the origin of technology fusion strategies and finally,
- Technology fusion strategies can lead to business diversification while having a strong rejuvenation impact with the new markets and opportunities they create.

The following sections provide some 'empirical' illustrations of these arguments.

Rejuvenation and materials. Rejuvenation is usually *the first step or the re-entry point* of companies or even industrial sectors in decline which, however, possess well established but old-fashioned materials capabilities. Significant improvements of

[12] The Hansen and Serin (1994) study, on the Danish plastics industry, and the Madsen's study (Madsen 1991) of the Danish pipe and window production, support the "process paradigm" by which they mean it is the material and the production process used by the firm / industry rather than its product that form the point of departure for the innovation and adaptation process.

properties and performance of existing materials and major improvements during their production are major rejuvenation agents. A typical example is the new structural steels produced by British Steel such as the revolutionary SLIMDEK structural steel presented in **Box 3.3**.

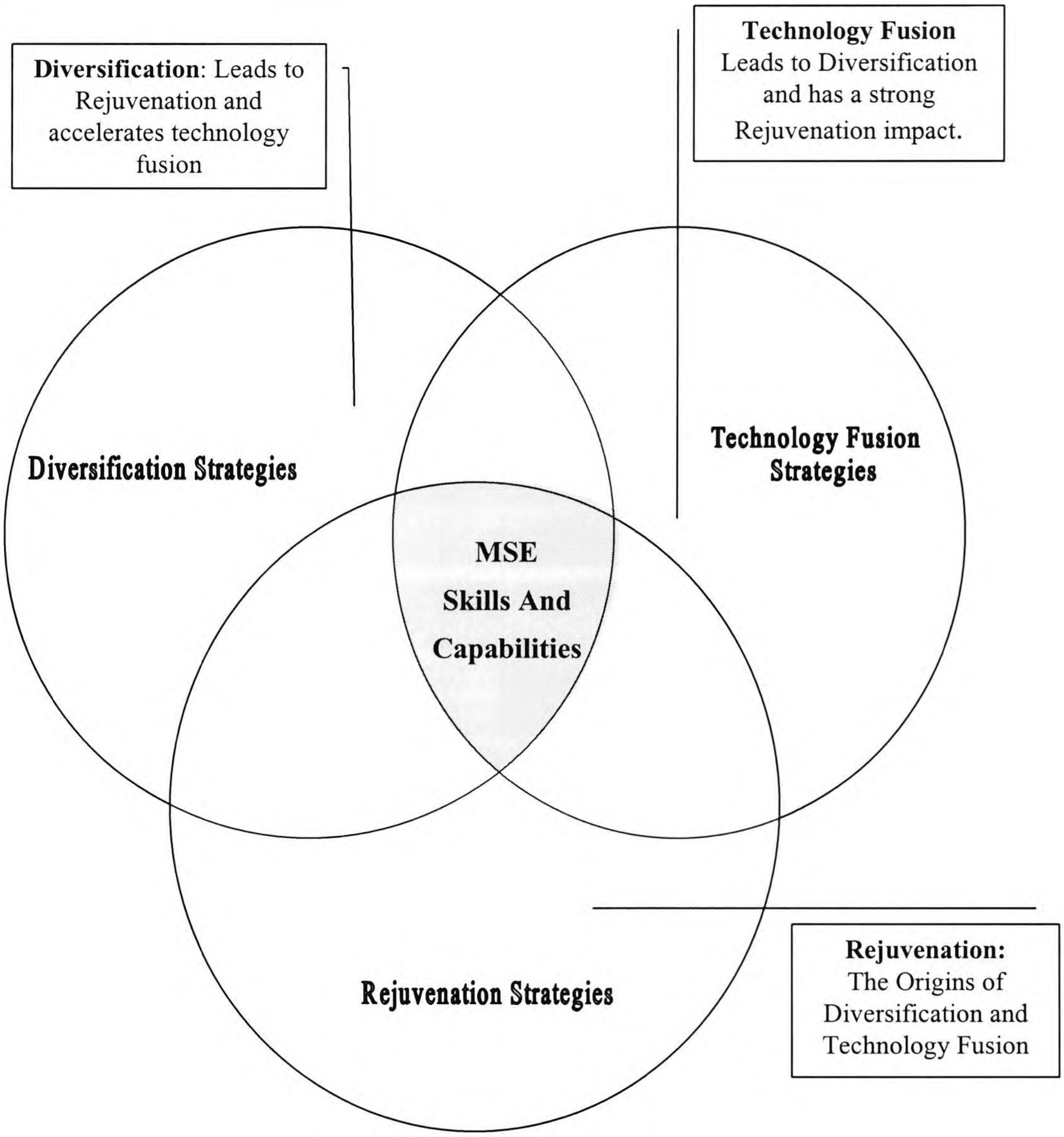


Figure 3.2: Materials Science and Engineering and Corporate Business Strategies. (Source: Kottakis 1999).

Moreover, it should not be a surprise that most of the optical fibers producers trace their history to glass making, while many South Korean semiconductors firms were commodity ceramics producers and some textile firms have developed expertise in advanced composite materials development.

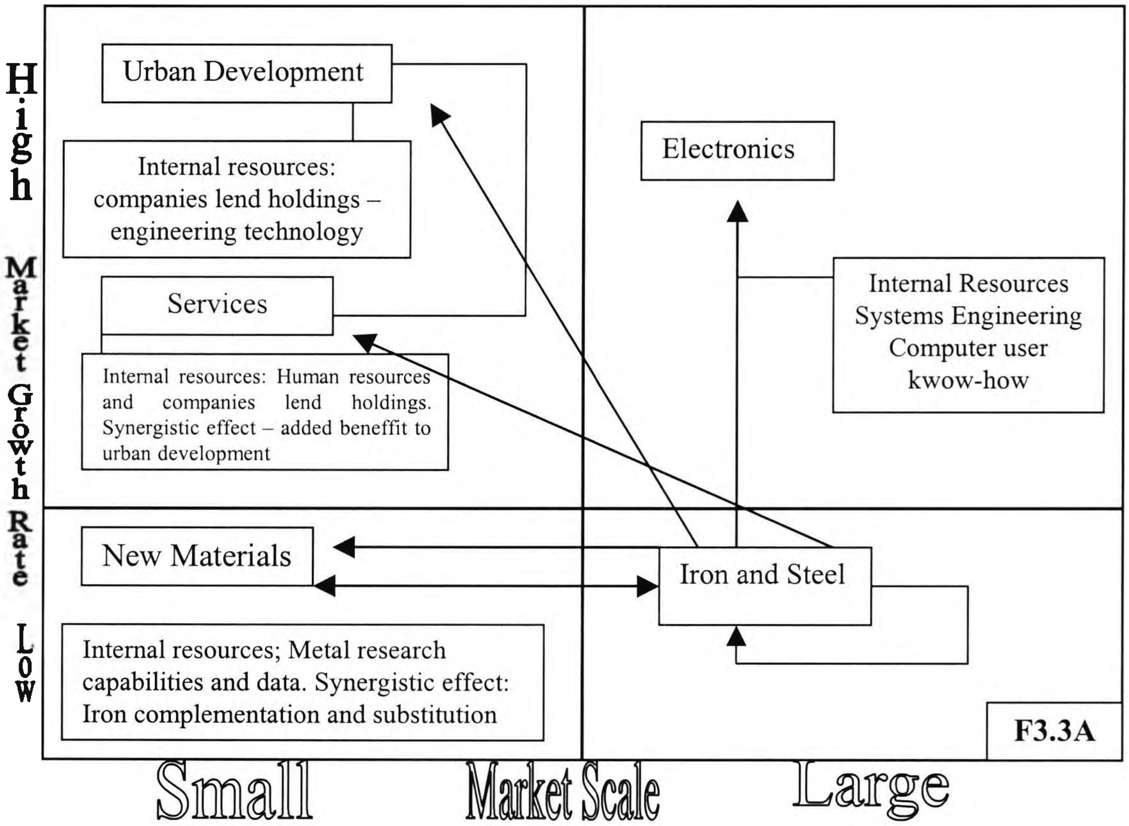
A rejuvenation strategy provides the opportunity of re-entering international competition and has initially the character to protect and secure markets under attack or to re-enter lost markets. As the above examples demonstrate, materials based rejuvenation/diversification strategies literally saved firms and industries from shut down and transformed them into advanced technology enterprises.

The most significant innovation in 40 years... The SLIMDEK asymmetric steel beam for construction and other structural applications, has been developed by a co-operative programme between British Steel, the Steel Construction Institute and the University of Cambridge under the auspices of the LINK Enhanced Engineering Materials programme. By heavy use of computer assisted modelling and simulation of the evolution of stress and microstructure in the beam during the rolling, cooling and straightening process, British Steel was able to produce a beam 25% lighter and considerably cheaper to produce than conventional steel beams allowing considerable services layouts and saving construction weight. In addition, the shape of the deck of the beam and the thermal capacity of the slab provide simple options for build-in natural ventilation, night-time cooling and air circulation within the troughs-key concerns for energy and cost efficient building management. The newly developed product is expected to transform the construction industry and lead to sales of more than 100,000 tons a year around the UK alone. It is claimed to be the most significant technological innovation in steel construction for over 40 years.

Box 3.3: MSE and rejuvenation strategies: the case of the SLIMDEK steel beam (Source: Anonymous, *ForesightLINK*, August 1997, pp. 6-8).

Diversification and materials. Diversification strategies based on materials capabilities are usually adopted by corporations or firms whose primary products or services are, or it is predicted that they will be, under fierce attack from current or future competitors. Until recently, diversification was motivated by reasons such as escaping from recession and transferring surplus personnel to new fields as part of restructuring programs. Diversification examples coming from corporations such as Nippon Steel, Alcoa and Toray Industries, demonstrate that materials-based diversification can be a strategically aggressive option and not a defensive move against external pressures.

For example, Nippon Steel deploys its R&D and business activities into a wide range of different areas (see **Figures 3.3a & 3.3b**) many of which use its accumulated experience in steel technologies and electronics in production processing and quality control. Alcoa, one of the largest world providers of alumina powder, building on its traditional strengths in ceramic powder technologies, established an advanced ceramics R&D department dedicated to the aim of developing monolithic, monocrystalic materials and ceramic based composites for electrical and electronic applications. But the best example, perhaps, of how strengths in the materials base can be used as a major source of business diversification, rejuvenation and technology fusion comes from the technology and business policies of Toray Industries in Japan presented in **Box 3.4** and **Figure 3.4**



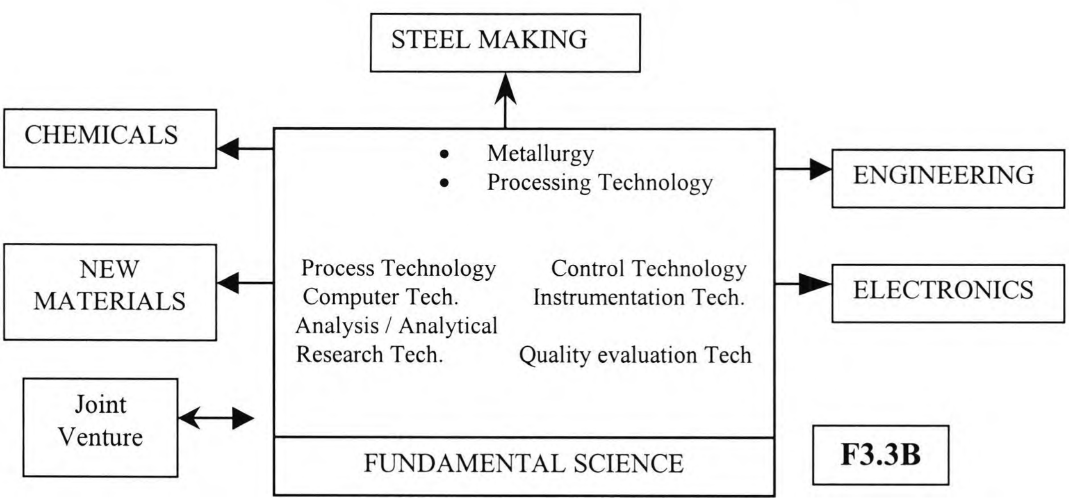


Figure 3.3a: Diversification Matrix of Japanese Steel Industry. (Source: Kaounides 1994 on information of industrial Bureau of Japan).

Figure 3.3b: Business Diversification Linkages. Synergies between high technologies accumulated in Steel making and business diversification areas – the view of Nippon Steel. (Source: Kaounides 1994 based on information provided by Nippon Steel).

Undoubtedly, Toray Industries strategic approach exemplifies the trends identified in previous sections. In addition, the Toray case study clearly indicates that there is a strong connection between materials based diversification strategies and materials motivated technology fusion efforts.

Diversification case study: Toray Industries, Japan. Toray Industries Inc. is Japan's foremost manufacturer of synthetic fibers and textiles, high performance films and engineering plastics. In addition, Toray is a world leader in the development and production of advanced composites and the world's leading carbon fiber producer. Utilising its distinctive technological strengths the company has diversified into chemicals, pharmaceuticals, medical supplies, electronic materials, housing and construction materials, and engineering. Toray operates a global marketing and manufacturing network of over 180 subsidiaries and affiliated networks.

Toray Industries in Japan was originally a traditional textile company. During the last 25 years Toray has built upon its core competencies and skills related to fiber technology, materials and chemicals *(pitch)* and through strategic technological alliances (see also chapter 4) has been completely transformed into a high technology advanced materials producer. Traditional textile producing units are still strong and in some cases they support financially units related to the development and fabrication of AM such as advanced composites for aerospace applications. As the applications have been expanding into diversified industrial fields, research to expand applications inevitably becomes interdisciplinary.

According to Toray this inevitably leads to the formation of alliances with final materials users and materials producers. Toray is in close co-operation with the aerospace industries, chemical industries and more recently construction industries. The concurrent development of a basic material with the user's development of a particular final product usually involves an enormous amount of development cost, risk and capital expenditure which can be overcome only by collaborative approaches.

Box 3.4: Diversification case study: Toray Industries, Japan (Source: Toray Industries 1992).

Technology fusion and materials. According to Kodama, (1992), technology fusion is the most powerful drive for technological change and will be the basis of competitive advantage in the future. In similar tune, the German Ministry of Education, Science, Research and Technology (BMBF 1993), argues that the interfaces between established fields are good places to look for new technologies. Technology fusion is intrinsic to demand articulation[13] and consists in combining existing technologies into hybrid technologies using a non-linear, complementary and co-operative way.

Technology fusion blends incremental technical improvements and achievements from several previously separated technological fields to create new "products" technologies and services. As such, its design and execution calls for high levels of organisational and management skills[14]. The technology fusion approach is complementary to the technology breakthrough approach. According to Kodama, focusing on breakthrough approaches alone finally fails because it focuses R&D

[13] That is building customers vague demands and "dreams" into R&D projects.
[14] Demand articulation, intelligence gathering and R&D mechanisms. For details see chapter 4.

efforts too narrowly. To be effective companies need to include both breakthrough and technology fusion approaches in their technology strategies.

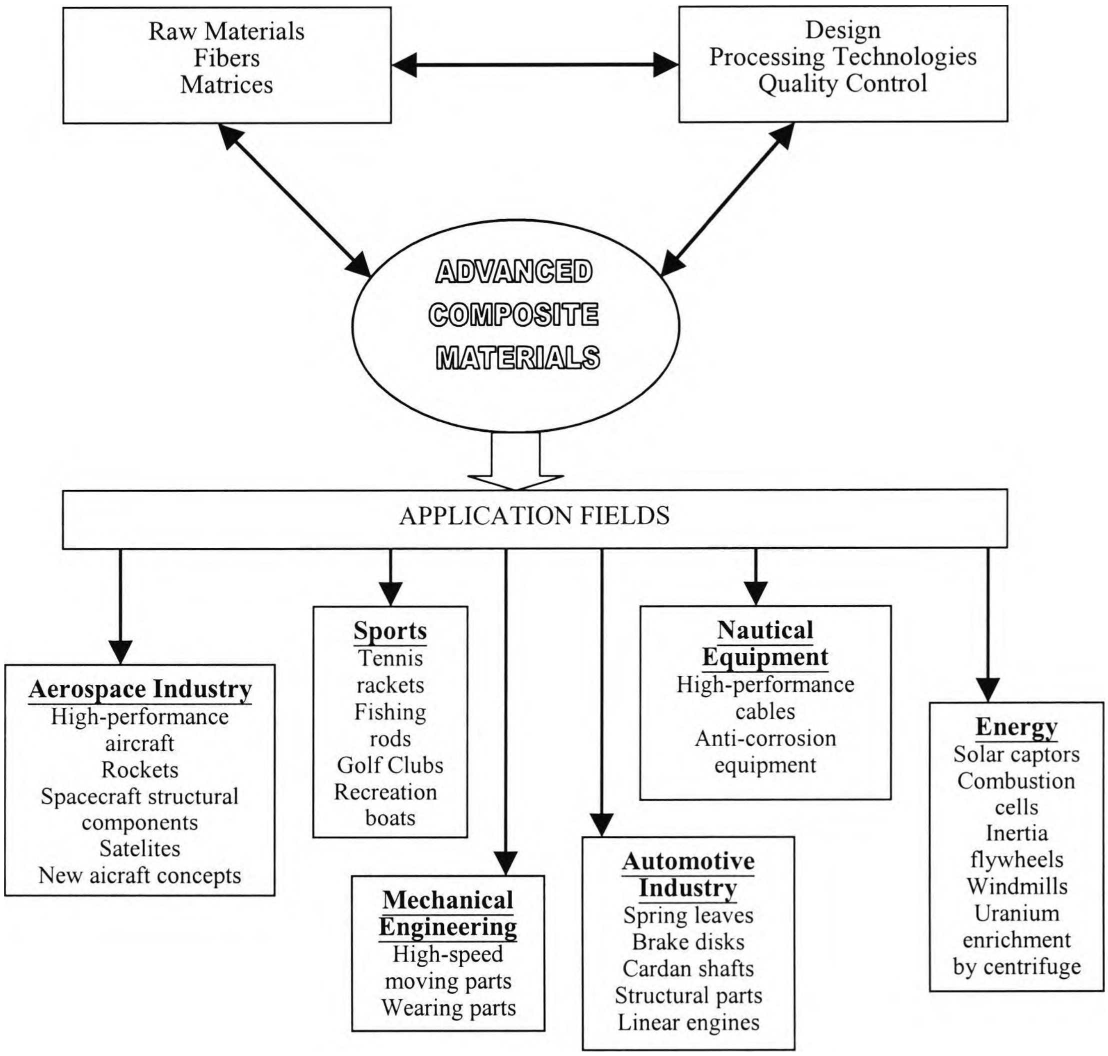


Figure 3.4: Diversity in the applications of materials according to Toray. (Source: Toray Industries 1992).

Collaborative R&D and diversification strategies -when seen as a strategic choice- accelerate and smooth the path to technology fusion, which at least in Japan and Germany is perceived as the tool to create new technologies and products that will revolutionise markets, offer new competitive advantages and create new markets and businesses.

Since materials technologies are a generic and enabling group of technologies it is not a coincidence that in numerous cases it is exactly materials progress or materials related R&D results which act as pilots or foundations of technology fusion efforts. Some characteristic examples are:

Optoelectronics: by bringing together optics, information technologies, electronics, materials and materials technologies the result was fiber optics, advanced communications systems, (largely materials technology and product), and optoelectronics sensors and processors equipment. Materials hold a central role in this technological fusion because AM like optical fibers and relative processing technologies, are the enabling factor upon which optoelectronic technologies are based (OECD 1993c). To produce optical fibers for example, technologies from glass and wire manufacturing have to be brought together, combined with principles of chemistry and surface science.

Nanotechnology: there is a great concern in modern manufacturing in controlling materials structure at the grain scale as well as at much finer levels. As a result, there is a new emphasis in the nanometer size regime, the intermediate between the macroscopic and the atomic level. By bringing together a large array of technologies and scientific areas (including electronics, sensors, advanced manufacturing systems, materials technologies and many others) efforts on S&P have focused increasingly on the nanometre size regime creating a new technology called nanotechnology. Nanotechnology is characterised as one of the emerging and most promising technological areas for the 21st century[15] (Scientific America, Special edition 1995).

Sonochemistry: sonochemistry involves using ultrasound to create tiny solution bubbles that then are allowed to collapse, accelerating chemical processes. The resulting shock waves create severe local reaction conditions - of the order of 5000 ^{o}C and 2000 bar - that can increase the yield of chemical reactions by 50% to 90%.

The above examples indicate that in the future technology fusion will occur more frequently between industrial sectors and materials, and materials technologies will be one of the main direct drivers - not just enabling factors - and parameters of this fusion.

Conversely, the trend of materials fusion is drawing on biology, chemistry, MSE and manufacturing to create the "fourth generation" of materials which will allow engineers to custom design new materials by manipulating atoms and electrons (Drexler 1992). Many high technology companies are already taking steps to harness the power of this generation of materials. The main actors in future materials

[15] "Increasingly the properties and performance of materials are determined by nanostructures and economy and society is using more of these materials each year. Development of such materials presents a scientific and technological frontier with enormous commercial applications to many industries" (Scientific America 1995).

developments will not just be the materials producers but also the manufacturers and *materials users* who will use the materials technologies to solve specific demand problems. In view of the above, the message to management is clear: technology fusion increasingly involves materials elements, and is becoming an increasingly important strategic choice for creating new products, materials and technologies.

3.7: Implications for management and conclusions

According to the findings of the preceding sections, the development and employment of materials competencies is a strategic necessity because advanced materials technologies are in many ways one of the corner stones of both corporate and industrial response to technological and business competition intensification.

Therefore, the strength and importance of the argument for integrating materials strategies and capabilities into technology and business strategies brought up for the first time in chapter 2 is verified and further strengthened here.

The introduction of materials innovation however, is a very complex issue as it directly affects the technology, manufacturing, organisational and operational status of the corporation / industry. **Figure 3.5** schematically summarises the three levels of the interaction between MSE and the corporation:

There is a direct action on the formation of the technology strategy and the R&D portfolio of the corporation where the core of skills and the technological knowledge are met, a direct action on manufacturing practices where knowledge and skills are turned into products and services, and an indirect action on business strategies which is formed at senior management and strategic planning level.

With respect to the latter (decision level), benefits and capabilities coming out of the interaction between materials and the technology and manufacturing base of the firm become the enabling tools for decisions implementation and/or provide the foundations upon which business policies will be based and decisions will be taken.

In many cases it is the requirements of the materials integration into the R&D, technology, manufacturing and business strategies that determine fundamental parameters of the corporate technology, manufacturing and business strategy. And it is competencies acquired from the optimisation of this integration that in many cases dictate business and decision directions.

It follows that in order to optimise the integration and interaction between the MSE field and the corporation's technology and business strategy and maximise the benefits originating from this interaction, some basic prerequisites should be in place (or developed simultaneously with the development and execution of this interaction)

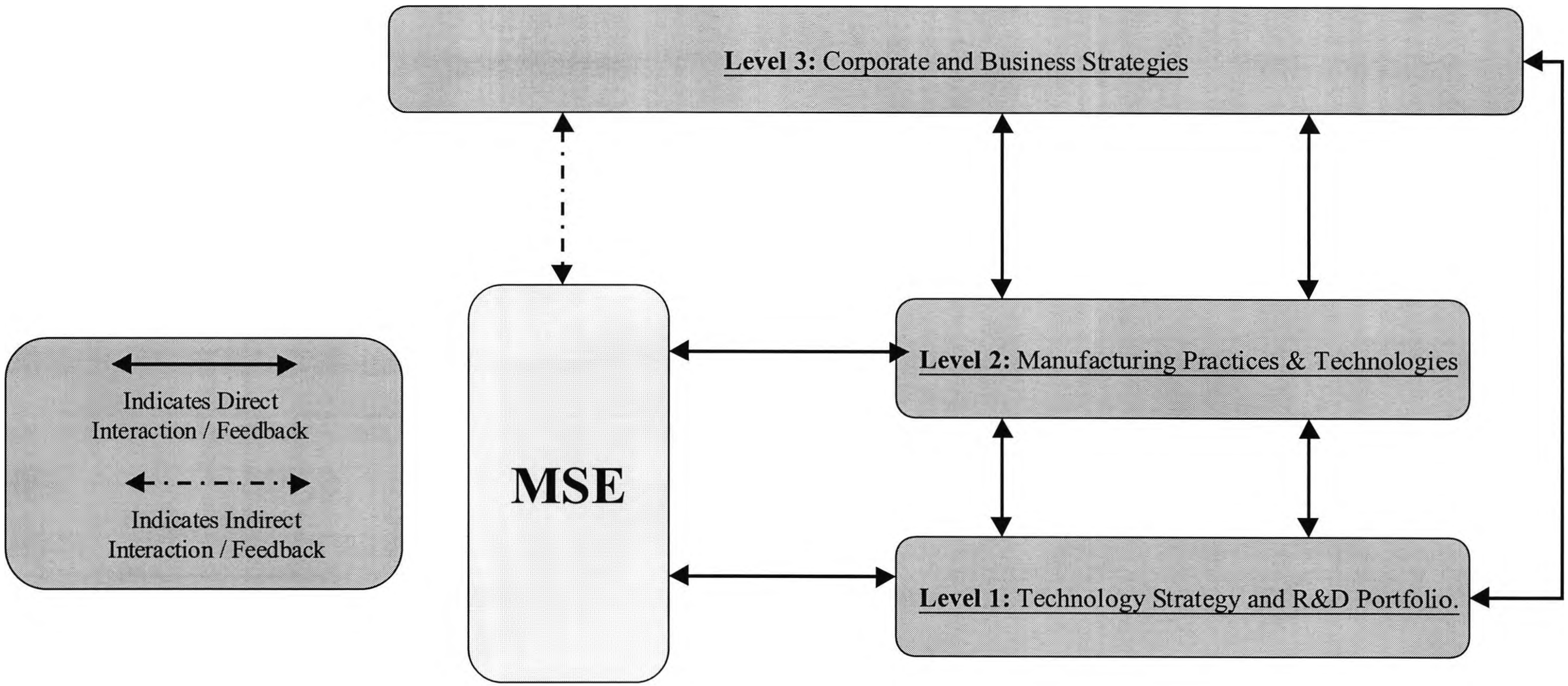


Figure 3.5: The interaction between Materials Science and Engineering and the Corporation (Source: Kottakis 1999).

while the appropriate technological and management basis should be present to support it and benefit from the opportunities it has to offer. Hence, the analysis offered in chapters 2 and 3 indicate that senior management could consider and address the following issues and findings.

** The first issue addresses the question of *under what management tools and methods* the above described interaction can be optimised and under what management practices the benefits of this interaction can be maximised. Chapter 4 argues that a specific set of management tools and methods, namely Kaizen, Lean Production (LP) and Simultaneous Engineering (SE) have the advantage of offering both interaction optimisation and benefits maximisation. To take it one step further, chapter 4 argues that the interaction of this particular set of management methods with the MR and the MSE field provides one more source of competitive advantage.

** The second issue deals with *the R&D role* and importance. Chapter 4 suggests that the R&D role is crucial because R&D strategies act as the catalyst in the interaction between MSE and technology and business strategy while the most fundamental aspect of a well directed technology policy is probably the formation of a well directed and focused R&D policy. If a specific manufacturer / services provider does not develop in-house R&D materials capabilities in agreement with their basic technology and business aims and needs, they risk to find themselves displaced soon by *former suppliers or competitors* who will develop their own capabilities and, finally, products.

** The third issue includes the need for entering long-term *technology-based alliances* in the MSE field and the necessity to identify, monitor, manage and protect the *basic core competencies* of the corporation. Section 3.5 identified that technology fusion and diversification strategies based on materials capabilities are usually materialised through co-operative, interactive and collaborative process. For that reason and for many other reasons (see section 4.3) the establishment of well directed technology- based alliances and the strategic management of the technological core competencies of the corporation becomes essential.

** The fourth issue addresses the *implications for management competencies*. According to Chelsom (1996) and Chelsom and Kaounides (1995), the formation of strategic alliances, defining and protecting core competencies, integrating business, technology and R&D plans in a complementary manner, requires a new type of management and new styles of management planning. According to Chelsom and Chelsom and Kaounides there is a major management education issue to be addressed at both corporate and national level. The issue is investigated in more detail in chapter 5.

** Finally, the appropriate corporate organisational structure including a number of internal competencies such as demand articulation and intelligence gathering mechanisms and in-house simulation and modelling skills should be in place, designed to support the above mentioned structures. We note that strategies are developed and implemented across existing organisational structures, which also need to change over time in line with the requirements identified above.

Conclusions

- Globalisation intensifies manufacturing, services and markets competition. Much of competition intensification is technology based.
- Technological change, emerging technologies, manufacturing, and lately services innovations are materials dependent and in the majority of cases materials constrained. Therefore, technological competitive advantage and further technical progress depends on materials technologies.
- Materials and the MSE field offer considerable opportunities for business competitive advantage because materials technologies *are generic and enabling* technologies able to support the development of many other technologies, products and, finally, business directions and decisions. As such, materials-related knowledge and skills should be increasingly recognised as one of the fundamental core competencies of firms / corporations. In numerous cases they have become the origin and/or they largely determine the degree of "achievability" of diversification and technology fusion strategies, technological alliances and joint venture formations.
- With the above in mind, materials strategies should be fully integrated into the technology and business strategies of the corporation / firm.
- To optimise this integration and maximise its benefits, some basic prerequisites should be in place (or developed simultaneously with the development and execution of this interaction) while a strong technological and management basis should be there to support it and benefit from the opportunities it has to offer. These include the adaptation and application of specific management tools and methods, the selection and management of the R&D portfolio, the identification of core competencies and the formation and management of technology based alliances and the existence of strong organisational structures including demand articulation and intelligence gathering mechanisms designed to support the above mentioned structures.

These issues are addressed and further analysed (at corporate level) in Chapter 4.

CHAPTER 4: Management implications and requirements for advanced materials technologies

4.0: Introduction and chapter summary

Chapter 4 addresses the issue of the materials revolution and industrial competitiveness at a corporate level. Chapters 2 and 3 argued that the integration of materials strategies into technology and business strategies is crucial for maintaining competitiveness in the new, technology-intensive business environment. The critical question is not only which corporation has focused its attention on MSE capabilities and opportunities but to what extent it can fully integrate all aspects of MSE into its manufacturing, technological and business environment.

Chapter 4 argues that in order to achieve and optimise this integration and simultaneously maximise its benefits, a number of basic management and organisational requirements and conditions must first be satisfied. These prerequisites are mainly imposed by the complex and multidisciplinary nature of the MSE field and they can be organised under the following conceptual entities:

- Specific management and manufacturing tools and practices (namely Kaizen and Simultaneous Engineering) which can provide significant advantages over competitors,
- The existence of a well-defined R&D strategy integrated into the aims of the corporate technology and business strategy,
- The identification and management of corporate core competencies and the formation and management of technological alliances (when necessary), and finally,
- The development of corporate core competencies necessary for the support of materials activities and the development of communication mechanisms with both customers and (services and materials) suppliers.

The chapter addresses these issues at corporate level within the context of their interaction with the MR and the MSE field. Section 4.1 provides a brief analysis of the modern manufacturing and management trends (e.g. Simultaneous Engineering and Kaizen) within the context of their interaction and connection with the MR and the MSE field. The section argues that the coupling of these management practices with materials competencies provides an additional source of competitive advantage.

Section 4.2 is dedicated to the issue of corporate R&D strategies and their connection with materials R&D and technology strategies. This part begins with the identification of modern R&D trends and organisational approaches within the context of the corporation's technology and business strategy. It then discusses organisational characteristics of R&D strategies dedicated to materials and MSE technologies including optimal R&D portfolios, materials development stages and time-based frameworks. Section 4.3 examines the issue of technological and R&D alliances in the area of materials technologies and argues that alliances between technological equals with complementary skills and opportunities for synergy (e.g. materials producers and uses) provide the best competencies. Section 4.4 addresses the issue of the identification and management of technological core competencies and capabilities for materials R&D. The issues of the management of technological alliances and core competencies are closely related. Section 4.5 presents an additional number of core competencies and organisational capabilities essential for the support of materials (and other technologies) R&D activities.

In section 4.6 the discussion takes a more general form and addresses issues applied to all materials-related industries such as new emerging roles and relationships for materials users and materials producers, emerging patterns in materials supply and MSE strategies suitable for Small Medium Enterprises (SMEs). The chapter concludes with a brief list of general recommendations for industry and corporations.

4.1: Materials Science and Engineering and the new manufacturing and management trends

The first issue to be addressed is the question of with what management tools and methods the materials integration into the corporation's technology and business strategies can be optimised, and with what management methods the benefits of this integration can be maximised.

Arguably[1], from the several management practices employed by world class companies, a specific set of practices namely Kaizen (Ky'zen), Lean Production (LP) and Simultaneous Engineering (SE) provides important advantages when the aim is to achieve and simultaneously optimise the materials - technology - business strategy integration. To take the argument one step further, Kaizen, LP and SE techniques are the most important management prerequisites to the effective development and

[1] Kaounides (1994, 1995), Chelsom & Kaounides (1995), Chelsom (1994, 1996), Sengenberger (1992), Imai (1986).

delivery of materials (and other technologies) competencies and are ideally suited to deal with interactive and complex issues such as technological innovation and commercialisation, from the point of view of the materials revolution.

4.1.1: What are Lean Production (LP) and Kaizen?

First of all the terms Kaizen and Lean Production do not simply define manufacturing systems. They imply a synergistic action of a family of activities (see Box 4.1: The LP system and Box 4.2: The Kaizen concept) with one central aim: maintaining competitiveness by maximising operational effectiveness over a long period of time. As it can be seen from Boxes 4.1 & 4.2, there are many common and complementary themes between LP and Kaizen but LP and Kaizen are not the same thing.

The Lean Production (LP) Tool Box

"LP is a better way of making things which the whole world should adopt... as soon as possible" Woomack, Jones, and Roos (WJR) (1990): *The machine that changed the world* [p. 225]

According to this approach WJR assert that the Japanese are capable of producing faster, better, and cheaper in Japan and elsewhere. According to WJR, LP is the system which among many others harmonically couples the strengths and advantages of Ford's Mass Production with the almost forgotten skills of the craft-based production which was replaced by the mass production in the beginning of this century. The principal features of LP are:

The LP Tool Box

- Simultaneous Engineering (SE) in product development,
- Just - In - Time (JIT) production, (zero buffer principle) ,
- Total Quality Control (TQC),
- Team Work (Organisation of workers into self-managed flexible groups, each with a team leader).
- Integration of the supply chain: Organisation of suppliers and co-ordination with the JIT principle.
- Co-operation: Co-operative relations within the firm / factory complemented by collaboration between end producers, suppliers, subcontractors and customers.
- Continuous Incremental Improvement (Kaizen) which is defined in LP as a collective process in which getting advice from every body in order to improve the product or the production process is crucial. The involvement of all employees in the process of improvement mobilises all available knowledge for the operation of the plant and serves personnel development through a continuous learning process.

These elements of LP, taken individually are not necessarily new. What makes LP different is that they combine and mould into a single coherent field and management concept. The elements complement and reinforce one another. For example: TQC becomes imperative under a JIT regime of manufacturing because faulty parts upset production and delivery schedules and underlines the avoidance of waste. In the absence of buffer stocks JIT depends on TQC, and to attain TQC a continuous improvement and monitoring mechanism is necessary, which in turn requires collaboration at all levels and a well trained and multi - skilled workforce.

Lean Production is the term first applied by the MIT study in 1990 to describe the Japanese approach to manufacturing, suppliers, customers, and product design. Hence, it is the Western view of the Japanese system. The Japanese view of the Japanese system of manufacturing is provided by Kaizen (Box 4.2) which emphasises continuous improvement, an aspect missed by the MIT study.

BOX 4.1: The Lean Production System (Source: Woomack, Jones and Roos (1990), Sengenberger (1992)).

Lean Production is the term first applied by Woomack, Jones and Roos (1990) in their effort to analyse the Japanese approach to manufacturing, suppliers, customers, and product design. It is a collective management tool / method aiming to optimise manufacturing (or services production and delivery) performance and operations. LP is based upon the Kaizen concept and philosophy, however, as expounded by Woomack, Jones and Roos, it missed one of the basic concepts of Kaizen: the concept of continuous improvement.

Basic concepts of Kaizen. Kaizen (Ky'zen) is both a management concept and a philosophical approach to problems (Imai 1986). The Kaizen tool-kit (see Box 4.2) has a much wider spectrum of applications than manufacturing because its basic principles and concepts can be applied to optimise and maximise the operational effectiveness of any complex system or system of interactions while simultaneously improving it, independently of scale[2]. That is because Kaizen has been developed along some fundamental base lines such as customer orientation, continuous improvement, and strategic attitude to cost reduction. In more detail:

** Kaizen *per se* means **continuous improvement.** When dealing with a complex system defined by the action of many synergistic parameters, a long-run, dynamic, continuous improvement approach must be incorporated in order to achieve simultaneous optimisation of effort and results. The continuous monitoring, correction and if necessary re-adjustment of the operational process is by default an incremental approach and reflects the philosophy that **experience is valuable, you learn by doing** and **you learn as you go**[3]. This approach can be applied to optimise and maximise the operational effectiveness of any complex system or system of interactions while simultaneously improving it, independently of scale or size.

** **Customer orientation:** Kaizen management strategies focus heavily on customer needs and engage in detailed studies of future life-styles and user requirements. Having this as their initial point they proceed to design and develop the relevant product or service[4]. Subsequently, they have to examine which in-house or globally available technologies will meet the current and future customers' requirements or "dreams" and tailor materials and other technologies to meet these "dreams". This necessitates the possession of deep knowledge of the capabilities of existing technologies and materials and the potentials offered by future technologies, while it provides vision and reason to management to be entangled in long-run strategic

[2] The Kaizen mentality can be applied to optimise a technology based alliance, the design of an R&D portfolio, a large construction project or even the drawing of governmental technology policies.

[3] The continuous improvement concept is very flexible to change because it includes the concept of dynamic change. Therefore, the learn-as-you-go is not incompatible with "learning-by-interaction" because interaction is necessary for learning (see section 4.3). On the contrary, the two concepts are complementary and cumulative.

[4] This point is also related to the technology fusion and demand articulation concept in Japanese management practices as discussed by Kodama (1991, and 1995).

responses and be committed to long-run R&D programs involving customers or users. But such commitments require a lot of information and knowledge exchange. This necessitates the formation of strong networks of collaborations and alliances between companies, research institutions and governmental agencies.

The Concept of Kaizen

According to Imai (1986) Kaizen is the best philosophical underpinning for the best in Japanese management. Kaizen is a management practice and starts with the recognition that any corporation has problems which can be both uni-functional and cross-functional (e.g. developing a new product or applying a new material into the production line/product.) Kaizen has enabled Japanese management to take a collaborative, systematic approach to cross-functional problem solving. Further, Kaizen recognises that customer service and satisfaction is the primary target. Improvements adjusted to new challenges every day in quality, cost and scheduling are essential. The essence of Kaizen is simple: it means management of change and continuous ongoing, incremental improvement in a process where everybody is involved and participates. To achieve that, a number of management practices have been developed whose synergistic action can be described with the word Kaizen. Kaizen is an *Umbrella* concept covering most of the new and not so new management practices that have recently achieved such world-wide fame.

The Kaizen Umbrella

Customer orientation
Kanban
TQC (Total Quality Control): Zero Defects & Quality Improvement
QC circles
Automation / Robotics
Just - in - Time (JIT)
Suggestion systems / Small group activities
Discipline in workplace
Co-operative management / labour relationships
TPM (Total Productive Maintenance)
Productivity improvement
New product development and **Simultaneous Engineering (SE)**

According to Imai (1986), the Kaizen way of thinking is the one that has generated these management tools. Further, according to some authors, (e.g. Kaounides 1995, Chelsom and Kaounides 1995) Japanese and Far East management is moving from people to technology oriented Kaizen. Here, not just everybody but all the available knowledge and experience will participate in the improvement process, enabling Kaizen to be able to cope not only with slow, incremental changes in traditional existing technologies, but also with the introduction and continuous improvement of new high technology products and processes and with sudden, rapid and one-shot major changes (breakthroughs) where traditionally the West is stronger. Kaizen among others creates "survivors" when drastic changes occur. These capabilities combined with IT and materials strengths provide a new edge for world competitive advantage.

BOX 4.2: The Concept of Kaizen (Sources: Imai (1986), Kaounides (1995/96), Chelsom and Kaounides (1995)).

** **Strategic approach to cost:** Kaizen recognises the new parameters affecting manufacturing and services as they originate from the continuously changing global environment and has a totally different approach to cost and cost reduction policy from the conventional. For Kaizen it is unacceptable to employ only financial controls, or squeeze R&D investment, or sacrifice quality in order to reduce cost or increase profits margins because these solutions do not offer any improvement apart from short-term gains. On contrary they define departure from facing a new challenge. This is a fundamental difference from the conventional Westerner mentality of cost reduction. Until the 1980s, the West has favoured 'supply push' cost approaches - "this is the best we can do; let's go and sell it" – whereas the Kaizen approach is: "this is what the customer wants; let's do all we can to supply it at a price they can afford and continuously improve each aspect of our operation so that we can do it profitably" (Chelsom 1996). The Kaizen cost approach provides the opportunity for a constant interlocking of all the involved elements and simultaneously improves the results, the processes and all the individual elements involved in both the design and the production and distribution of product or service.

4.1.2: The concept of Simultaneous Engineering (SE)

The aim of Simultaneous Engineering (or Concurrent Engineering) is to resolve the 'design dilemma[5]' and to eliminate (weed-out) the costs, inefficiencies, delays and dangers involved in 'over the wall' engineering and the sequential model of evaluating designs of new products and services[6] (Chelsom 1996).

SE provides the opportunity to bring together the downstream expertise of process and service engineers, machine operators, *materials* experts, materials and component suppliers, equipment suppliers, sales people and even financial analysts, at the same time and early enough, to resolve design and manufacturing concerns before production requirements of components and equipment are ordered.

According to Chelsom (1996), Simultaneous (or Concurrent) Engineering offers significant gains (summarised with **Table 4.1**) and enables materials and equipment suppliers, services providers and the so-called 'original equipment manufacturers' (such as vehicle, ship, aircraft, machinery or computer producers) to come together

[5] The designers' dilemma is the reconciliation of their own objectives with those of the production engineering, production, distribution and support activities (a set of conflicting demands/objectives in the design and development of a new product) (Chelsom 1996).

[6] Many attempts to resolve the design dilemma and to handle major business issues, founder when new product development is handled in a sequential way. If design for manufacture and for assembly are handled and tested by sequential trial and error, time is wasted and the design work has to be repeated. Moreover, the trial and error approach *for testing the effectiveness* of designs (of both products and services) can be extended beyond manufacturing to the customer. As in the materials case, performance in the market place and in use will show whether a product really has been designed for the required performance, function and longevity. This expensive and unsatisfactory way to evaluate designs has been labelled 'Over The Wall' engineering (OTW) (Chelsom 1996).

and resolve the design dilemma while simultaneously achieving all their fundamental business objectives.

Design decisions are critical. Traditional engineering is expensive: typical costs of each change during the linear (OTW) development of a major electronics component:			
When design changes are made:	**Cost ($)**	**When design changes are made:**	**Cost ($)**
During Design	1,000	During test production	1,000,000
During design and testing	10,000	During final production	10,000,000
During process planning	100,000		
Gains from Concurrent Engineering: benefits from designing manufacturability, quality and ease of maintenance into the product at the start:			
Development time	30-70% less	White-collar productivity	20-110% higher
Engineering changes	65-70% fewer	Dollar sales	5-50% higher
Time to market	20-90% less	Return on assets	20-120% higher
Overall quality	200-600% higher		
In addition (and in general terms) **it can be said that Simultaneous Engineering**:			
Reduces capital investment by 20% or more		Increases life-cycle profitability throughout the supply system	
Supports TQC with zero defects from the start of production, and with earlier opportunities for continuous improvement		Supports Just-In-Time production with total quality supplies, and advanced planning of inbound logistics	
Incorporates both incremental and radical technological change		Simplifies after-sale services	

Table 4.1: Gains from Simultaneous (Concurrent) Engineering (Source: Business Week Special Report, 30 April 1990, Chelsom (1996)).

Under SE practices the needs of customers can be expressed in non-technical terms such as product features or performance characteristics. It is then up to the design teams - which may or may not include customer or supplier technologists – to translate these wishes into technical specifications. However, it is more likely that technologists from (*materials* and equipment) suppliers will have more useful input into the design team rather than customer representatives alone. Indeed, in manufacturing industries[7], more than 60% of materials and about 90% of production equipment expertise comes from outside a given company. Hence, according to Chelsom (1996), and Chelsom and Kaounides (1995), an important early step is the

[7] The same logic or analogies apply to other industries.

recognition of this outside capability by the internal experts. This enables companies or industries to move from the stage where SE is seen merely as co-operation between design and manufacturing from within one organisation only ('*Closed SE*') to stages where inputs are contributed not only by one organisation but by the whole external supplier base and by customers simultaneously ('*Open SE*') in a spirit of partnership among different organisations.

Therefore, Simultaneous or Concurrent Engineering practically means tearing down walls between product design, materials selection and development, manufacturing techniques, marketing and management of producers or suppliers and replacing them with inter-disciplinary teamwork, co-operative approaches within and outside the boundaries of the company and constantly interacting, non-sequential evaluation processes.

4.1.3: Advanced Materials and Simultaneous Engineering: Competitive advantages and management implications

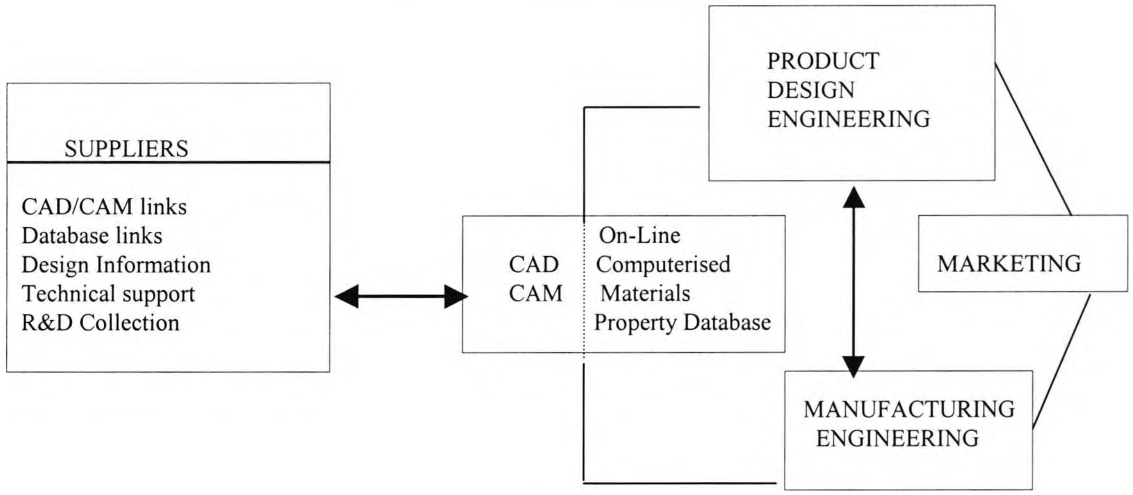
Chelsom and Kaounides (1995) argue that if the strengths and opportunities offered by advanced materials and the materials revolution are to be fully exploited, they *necessitate* the simultaneous design of the material, its manufacturing process and, the final product and its manufacturing process, that is SE practices.

The combination of Simultaneous or Concurrent engineering practices during product design with Information Technologies capabilities, and advanced materials and MSE strengths –tailorability of materials in particular - provides new dimensions to SE and enables both suppliers and 'original equipment manufacturers' to develop a new source of competitive advantage called by Kaounides (1995) Simultaneous Manufacturing (SM). The main characteristics and advantages of Simultaneous Manufacturing are summarised with **Figure 4.1** (as adapted from Kaounides (1994c)).

The combination of MSE strengths with SE practices however, entails a number of fundamental prerequisites, which, conversely, can provide additional sources of competitive advantage:

** **Standards and information compatibility:** The universal and compatible transmission of engineering and technical data is regarded as essential for the successful implementation of SE and the closer integration of users with producers.

SIMULTANEOUS MANUFACTURE



CHARACTERISTICS

- **Simultaneous Product and Manufacturing Process Engineering:** The engineering of entire products, systems or major sub assemblies. The engineering of components or individual piece parts.
- **Interdisciplinary Teamwork and Optimisation of Design and Process**
- **Computer-Aided Design (CAD) and Computer-Aided-Manufacturing (CAM)**: Use of computer facilitates close links between conceptual development, drafting and analysis. Use analysis during conceptual development. Build analytical models. Eliminate costly prototyping and iteration. Solid modelling. Expert systems. Computer networks.
- **Computerised Materials Property Data Bases**: Proliferation of materials necessitates that engineers have ready access to computerised databases containing continually updated materials availability and properties information Organisation of material properties in a manageable format. Search and evaluate materials for performance and cost. Integrate with CAD/CAM systems to support finite element analysis. Link materials selection to computer aided design. Candidate materials tested in optimised designs.
- **Statistical Approaches to Eliminate Manufacturing Problems at the Design Stage**: Statistical process control to gauge the accuracy of manufacturing methods. Statistical experimental design to improve quality and save costs by the generation of data necessary for the design of more reliable products and processes. Taguchi method and Robust Product Design method. Computer simulation of production methods.
- **Multiple, Interlinked Databases**: Diverse hardware architectures used in design and manufacturing systems must work together. Different databases across engineering, manufacturing, marketing and sales must be able to interact. Given wide variety of data formats, databases although decentralised must be inter-linked.
- **Collaborative with Suppliers and Contractors**: Formal and informal consultation with suppliers early in the design process. Firms may want direct computer access to contractors and suppliers databases and design information Suppliers may need to install similar hardware and software system for data management and exchange. Suppliers may need to demonstrate ability and skills in the use of statistical methods. Need to meet strict specifications and qualifications of user. JIT production and delivery.

ADVANTAGES

- **Design Determines 80% of Manufacturing Costs**: Hence manufacturing must be brought in early in the design process
- **Design for Manufactures and Assembly:** Simplify product and associated manufacturing and/or assembly process. Near net shape manufacture. Elimination of components, parts and assembly steps. Improve fitting and joining methods of components. Build quality into product and manufacturing process.
- **Results:** Compression of Product Development and Manufacture Cycle; improve time to the market; less number of defects; cost reduction; closeness to customers, faster product renewal, faster market response.

Figure 4.1: Simultaneous Manufacture: characteristics and advantages. (Source: Kaounides 1994c).

Especially when the issue comes to materials or to electronic data interchange and CAD/CAM, CNC and CIM compatibility problems, availability of technical data, standards and information compatibility is crucial[8].

** **Management requirements:** As the three graphs of **Figure 4.2** illustrate, the exercise of SE practices involves a rapidly increasing management complexity. The linear ('over the walls') process of new product development is ineffective and inefficient but fairly simple to manage. In SE the aim is to resolve the design dilemma internally and to make incremental improvements to known products and processes. Because design is by a team, relationships between individuals and organisations become more complex and hence more difficult to manage. In modern SE ('Open SE'), when revolutionary new materials and technologies have also to be considered, SE teams have to take into account radical change and possibly the complete replacement of products and processes rather than their improvement. Members of the team may have to be drawn from different industries, and from variable research organisations not familiar with the industrial and business world. Management of these new relationships in the new technology-based environment can become very complex.

According to Chelsom and Kaounides (1995) and Chelsom (1996), the increasing management complexity *necessitates* the employment of Kaizen management practices because they are designed to cope with change and to optimise the functionality and effectiveness of complex and interactive systems. Companies with fully implemented Kaizen management strategies can more easily and effectively move towards radical next-generation materials and information technologies within an integrated R&D and product development cycle to meet evolving customer needs. In fact, Chelsom and Kaounides argue that Kaizen techniques are a *prerequisite* to the effective development and delivery of new technologies and the implementation of SE practices and they are ideally suited to take advantage of the materials revolution.

The implication for both managers and scientists/engineers is that they too must be able to communicate (with marketing for example) if they are to contribute effectively to new product development and to work in teams with teams (Chelsom 1996). This necessitates 'holistic' management approaches and appropriate management education backgrounds.

** **Collaborative spirit**: The implementation of SE practices *necessitates* the formation of close collaboration between materials and components producers and final users and a thorough understanding on their part of the design / development

[8] See also chapter 5: Standards and Databases.

goals. Partners should not only stay together during design stages but also through the product or service development implementation stage. The exchange of knowledge and information is in favour of the materials multi-disciplinarity and tailorability and in favour of the process of integration of materials strategies into the corporate technology and business strategies.

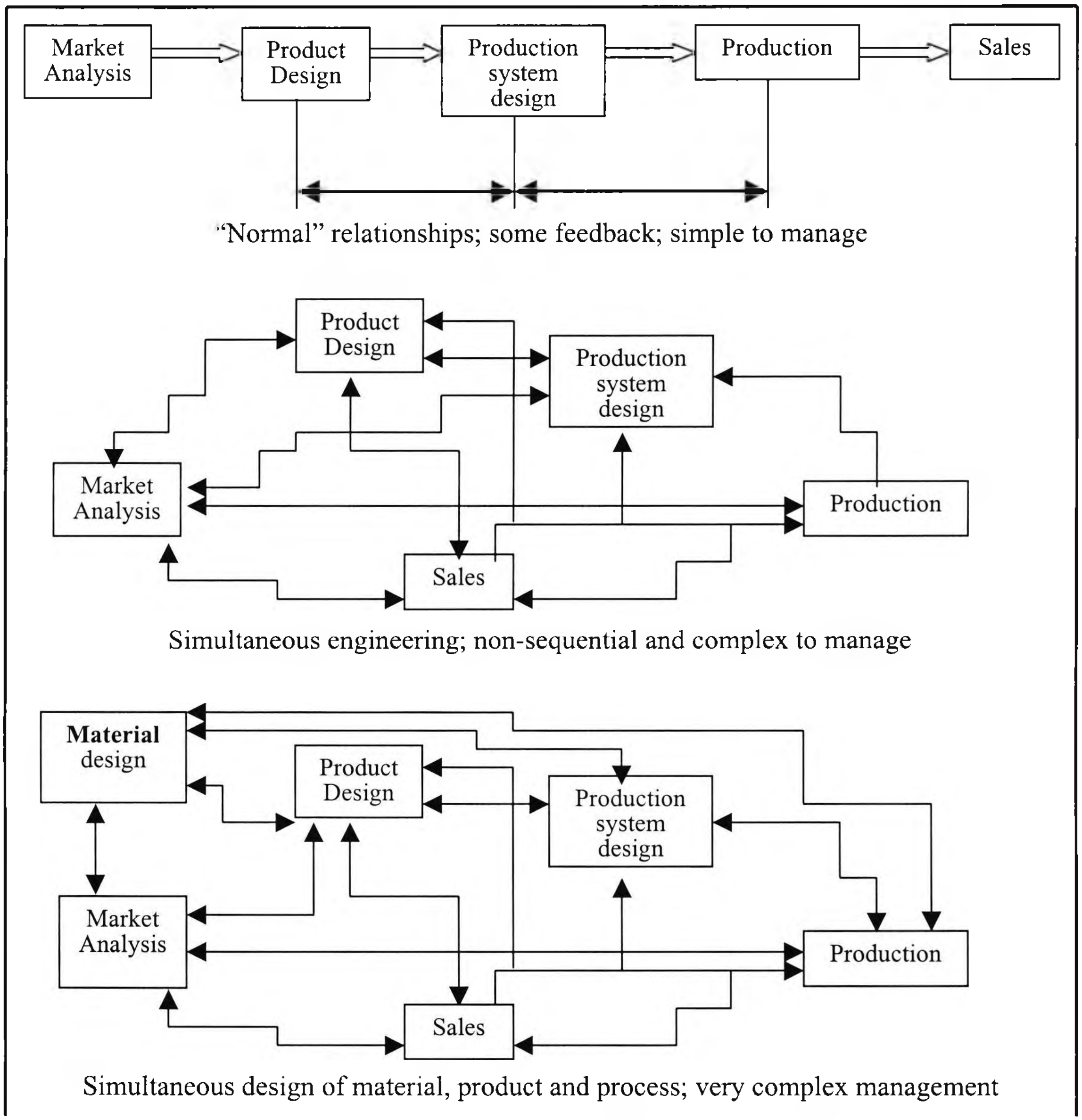


Figure 4.2: Simultaneous Engineering and increasing management complexity. (Source: Chelsom 1996).

A close collaboration of this type can provide a significant competitive advantage by enabling the creation of products and technologies tailored to meet the requirements of both consumers and socio-economic or environmental demands. If both the materials producers and the users are companies using SE and Kaizen principles, producers will develop capabilities enabling them to deliver complex advanced materials systems to final users and final users will acquire a deep understanding of materials and their requirements.

** **Time Horizons:** Rapid technological change and advanced materials technologies offer new opportunities and challenges to the designer. Having reduced the time from design to market launch, the new task is to close the gap between basic research and its commercial application. According to Chelsom (1996), SE teams have to broaden the coverage of their studies to cover not just incremental changes but also to include revolutionary new materials and processes. They also have to *lengthen* the time horizon so that the implications of using new materials are considered through to disposal or recycling. It follows that choices of this kind should have a time-horizon of a decade or more and not of a single planning cycle. Continuity fosters improvements in individual activities and harmonisation across activities, allowing an organisation to build unique core competencies and skills tailored - as materials can be tailored - to its strategic aims.

4.1.4: Kaizen, Simultaneous Engineering and Materials Science and Engineering: abstractive connections

In view of the above, companies with fully implemented SE and Kaizen management practices can more easily and effectively incorporate *both* incremental and radical technological change within integrated R&D and product development cycles in order to meet evolving, predicted or created customers needs.

According to Kaounides (1995) and Chelsom and Kaounides (1995) the next source of competitive advantage originates through the combination of MSE strengths with SE and Kaizen management methods. Given the role of materials in technological change, the role of SE in the design of new products, services and processes (where materials capabilities are fully incorporated) and the role of Kaizen in **operational effectiveness**, the combination of the three 'elements' achieves a very powerful and complementary **strategic fit** of actions, thereby providing a head-start in competitive conditions and a significant source of competitive advantage[9]. To put it more

[9] Since the success of strategy depends on doing many things well - not just a few - and integrating them, the integration between materials and technology and business strategies within the operational and methodological frame of Kaizen techniques provides the best fit possible between different elements of a competitive strategy and therefore a competitive advantage able to lock out imitators and late rivals.

formally, the tasks of the three 'elements' are reinforcing and complementary and they achieve a very good **"third-order fit"** (Porter 1996) as elements of an integral technology and business strategy (see **Box 4.3**).

According to Porter (1996), "fit" is a measurement of how much discrete activities are inter - related and integrated to each other. Good fit locks out imitators or competitors by creating an interactive structure that is as strong as its strongest element / link. In that way, the competitive value of individual activities cannot be separated from the whole. The "third - order fit" is the best type of fit because it simultaneously *achieves optimisation and reinforcement of both efforts and results.* Although some types of fit among activities are generic the most valuable fit is a third - order, strategy - specific fit because it enhances a strategy's uniqueness and amplifies competitive advantages and trade - offs (Porter 1996, Milgrom & Roberts 1990).

BOX 4.3 : The "Third-Order Fit". (Source: Porter 1996)

Leading companies have begun to identify these issues and move in the direction of organising and managing their R&D and product development functions in accordance with the new challenges. The R&D role and importance is the subject of the next section.

4.2: Materials Science and Engineering and R&D issues

Probably the most fundamental aspect of a well-directed technology strategy is the formation of a well-directed and focused R&D strategy. Therefore the way R&D is organised and implemented within the framework of the corporate technology and business strategy is of paramount importance. The aim of the following sections is to discuss the relationships between modern R&D strategies and the MSE field and to identify the organisational capabilities necessary for successful implementation of materials R&D strategies.

4.2.1: R&D and the management of technology

Why do firms need a technology strategy? Why does the firm need to strategically manage its technology base over time? According to some authors (e.g. Roussel 1991, Ayres 1988, Arthur D. Little 1992, Dussauge et. Al. 1992, Kodama 1992, Coombs et. Al. 1994, Kaounides 1995d) some of the relevant considerations are:

- Competitiveness and wealth is mainly derived from technological innovation.

- At the same time the international business environment is characterised by globalisation and an intensification of competition much of which is technology based.
- From aerospace to construction and from steel to software the pace of technological innovation is quickening, introducing what might be termed *time-based* competition in the new global business environment.
- Adding to the pressure, technological innovations (such as materials innovations) are increasingly crossing industry boundaries.

No longer can companies afford to miss a generation of technology and expect to remain competitive (Kodama 1992). Moreover, the need to continuously reduce product development cycles and to prepare the corporation for the next generation product and technology families has become a key requirement for all companies (Kaounides 1995). Failure to identify and address these issues "may be the most important source of competitive decline" (Dussauge et.al. 1992).

Hence, whereas in previous stages of industrial development the emphasis was on the application and development of pre-existing and globally available invention and technology, firms must now promote the development of in-house R&D capabilities which would underpin the emergence of a new generation of products and technologies.

These arguments point to the fact that technology and management of technology has acquired a critical importance in creating and sustaining competitive advantage in the world market. The accumulated experience of Arthur D. Little Inc. (1992) indicates that the most successful corporations:

> "...are those which have developed a clearly defined technology strategy which is then fully integrated to corporate strategy and managed at senior management level. The R&D portfolio, as it is continuously reassessed, dictates and finally predetermines the future technological capabilities of the corporation".

Materials technologies, and the developments identified in chapters 2 and 3, not only underline the importance and urgency of these issues but also establish the existence of a solid technology and R&D strategy as a fundamental prerequisite for successfully integrating materials strategies into the corporate/industry's technology and business strategy.

4.2.2: Recent R&D trends and philosophies

According to Roussel et Al. (1991) and Dussauge et Al. (1992) there are three generations of R&D management.

First generation: The 'blue skies' era. After WW II, the most common approach to R&D management was to treat R&D as a means to achieve technological self-efficiency and independence. R&D management and organisation acted with a large degree of autonomy without identifying strategic core competencies and priority areas. Management hoped that the R&D department would come up with something really useful for the business and manufacturing sectors of the firm. As a result, there was no guarantee that the programs pursued would correspond to corporate and competitive objectives. Unnecessary overlaps, lack of synchronisation, funding inconsistency and directing R&D to the wrong area (because market, design and manufacturing feed back was not involved) elevated both the cost and the inefficiency of any project undertaken. R&D expenditures were taken as an overhead and their budget was usually set on an annual basis as a fraction of profits or incomes, while the R&D function successfully resisted attempts to measure and quantify its outputs. Collaboration in R&D between firms focused mainly on technical information exchange, (many times the aim was to keep an eye on the opponent's capabilities) and on pre-competitive basic research. Co-operation in the development or sharing new technologies was not included.

Second generation: The 'net present value' approach for individual projects. Dissatisfaction with the results obtained from the first generation R&D model, and harsher economic and competitive conditions led to more rigorous approaches. Attention was focused on evaluating the cost effectiveness of the R&D investment expenditure. The move towards a more systematic R&D approach has led to the *"net present value"* rule in order *to offer financial justification* for R&D projects. Although this may have incremental contributions to value, it may have *little long-term significance* for the company because R&D expenditure is seen as a financial factor subjected to economical control and not as strategic asset serving the strategic planning of the company. An additional problem is that although each project may in itself be consistent with the objectives of the business, the total R&D portfolio may bear little or no relation to the overall corporate strategy. In this case, the technology base of the firm as a whole is not clearly recognised nor considered as a strategic asset, and tends therefore, to be eroded over time. Despite its weaknesses, the 'net present value' approach is still widely employed.

The 'Third generation' R&D: From the early 1980s and onwards, pressures originating from global competition gave roots to the idea that the *R&D portfolio* (and not just individual projects) must be fully integrated into the technology and business strategy of the corporation. The R&D portfolio, as it is continuously reassessed under constant senior management monitoring and supervision, supports, dictates and finally predetermines the future technological capabilities of the corporation (Roussel (1991), Dussauge et.al. (1992), Kaounides 1995d).

If these conditions are met the R&D activities of the corporation have the potential:

- To develop and deliver solutions for current problems and to fully support existing business;
- To prepare the ground, support or become the departure point for the 'materialisation' of emerging technologies and emerging business;
- To build and/or deepen the technological base of the corporation and increase its in-house skills of understanding providing a significant basis for the development of strong in-house core competencies (see section 4.4).

Under the 'third generation' philosophy, R&D *per se* is recognised as the most critical response to competition intensification. Deliberate efforts are made to design and implement a balanced R&D portfolio including both short and long-term projects according to the current and future objectives of the corporation. Long-term R&D projects are seen as drives for future growth, creation of new business and the pursuit of emerging technologies.

Time and money spend in third generation R&D portfolios are seen not as overheads but as strategic investments. As such, R&D budgets are financed directly by the business unit operating budgets and/or by a centrally co-ordinated R&D budget, with the balance varying between companies. Central funding is normally directed towards long-run technological development projects.

R&D management co-exists with business and product development management while the R&D portfolio is continually monitored and evaluated. R&D collaboration and technology based strategic alliances are viewed as a strategic competitive asset, holding an important role in the corporation's technology strategy.

Under these conditions, the selection of strategically appropriate R&D objectives and priorities and their **efficient management** from conception to implementation is of paramount importance. As Coombs (1994), Kaounides (1995), and Xiroyianni (1996) pointed out, the corporation which sets-up a corporate unit for the strategic design and management of its R&D portfolio and applies Kaizen techniques for its management is more likely to:

- Secure the mobility of technological capabilities across the corporation (including business units or geographical divisions),
- Identify and strengthen technological competencies that are required in more than one area,
- Integrate more successfully technology strategies into business strategies, and,
- Be able to analyse, acquire or develop emerging technologies for the creation of new business opportunities.

Further, the internal organisation of R&D, and the mechanisms by which it is linked to other business, technology and internal functions, not only reflects the R&D philosophy of the firm but it also largely predetermines its present and future character.

4.2.3: R&D organisational approaches

Corporate R&D portfolios vary considerably including projects focused on fundamental research, applied research, technology or product development, processing optimisation and even day-to-day trouble-shooting.

Since the late 1980s, it has been accepted that a corporate R&D portfolio maximises its efficiency (especially over long period of time) when it simultaneously includes and keeps the balance between basic, applied and near market R&D projects. As recorded case studies demonstrate (e.g. Rolls-Royce, Nissan, Toshiba, Daimler-Benz, Alcoa, Audi, Toray, Siemens, ICI, etc.), fundamental or precompetitive research projects provide new frontiers and new phenomena, new products or technologies development projects create new technologies, products and markets, and R&D during the commercialisation stage enables these new technologies and products to find their way to the industrial and production floor and be transformed into competitive advantages.

By accepting this philosophy, three main streams of R&D organisation approaches have been formulated: the centralised, the decentralised and the mixed.

The Centralised Approach: The centralised approach includes the creation of central R&D laboratories usually developed in specific geographic locations and supported by both domestic and international networks of linkages which function as feed-back or supporting mechanisms to the central aims and targets.

The centralised approach is advantageous when many of the corporate competencies and skills are required simultaneously or when the targets are simply too large or complicated for individual branches (geographical divisions) or individual business units. An additional advantage is the avoidance of duplications as high levels of co-ordination can be achieved. The concentration of resources and competencies enables the development of complex and expensive R&D portfolios, including areas focused on frontier developments, fundamental research, emerging technologies, new advanced materials, etc. which usually requires long-term commitments. It also offers better protection of "sensitive" cutting-edge research, directly related to the technological core competencies of the corporation.

The Decentralised approach: The decentralised approach chooses not to create large in-house R&D laboratories but to transfer R&D activities to the business units or the 'geographical' branches/divisions of the corporation (which can have both local and global presence).

The decentralised approach has advantage when technological or market specialisation is necessary. It also has the potential to make R&D portfolios more market driven and more agile, as communication with the markets, suppliers and customers is more direct and frequent. It is also more interactive (when compared to a centralised approach) as it regularly seeks to acquire external R&D inputs where and when required.

On the other hand, R&D projects under this approach tend to have short to medium term objectives concentrating on improvements in existing families of products or technologies, while focusing mainly on applied and near market research (Roberts 1995). As a result the corporation which chooses to have a decentralised R&D approach risks the possibility to create over-specialised, narrow focused R&D units and facing the danger of erosion of its scientific and technological base. Furthermore, the decentralised approach largely depends on good knowledge and information circulation to avoid duplications or internal conflicts and by default inserts a higher level of uncertainty as there is no real guarantee that all the necessary R&D information or resources will always be available when needed and where needed (especially if new technologies threaten existing business units).

The "Mixed" approach: This approach attempts to combine the strengths of the previously identified R&D organisation models. Good communication and co-operation at senior management level and clear but flexible division of R&D tasks are basic requirements for this approach.

Within this frame, the central laboratories, having been strengthened or re-established, usually focus on long-term complex problems (such as emerging technologies, new materials, new manufacturing technologies etc) reflecting the long-term visions of the corporation. The geographical divisions or the business units' R&D departments are then more application-oriented and they usually have the mission to optimise products and services and/or lead existing technologies, materials and S&P technologies to their limits[10].

In this model there is constant flow of information exchange between the central laboratories and the branches or the business units as findings, know-how and experience is circulated in the corporation. New technological trends are passed from the central laboratories to the 'periphery' while feed-back and knowledge acquired by the 'periphery' supports the activities and the decisions of the central unit.

Within this framework, there are cases where the central laboratories have a more predominant role and decisive influence on the formation of the R&D portfolio. The business units or geographical division/branches act as "market probes" and they perform R&D with relative freedom of choice (they have to satisfy their business needs). However, they have to harmonise their R&D portfolio with the general frame of the generic directions imposed by the corporation's R&D portfolio as expressed by the views of the central unit. In this approach the business units have a more "executive" character in the formation and implementation of the corporate R&D strategies.

There are also cases where the business units' opinion has a stronger role in the formation of the corporate R&D portfolio. In this case, each business unit or corporate branch is largely independent from the others in the direction and formation of their R&D portfolio. What is common and provides coherence is the strategic business objectives of the corporation which every unit has to meet. Common needs are identified (e.g. enabling and emerging technologies), and the central laboratories have the role to cover these needs. In this approach, the central unit has a more supporting and consultative role providing technological and scientific "back-up" while preserving its role for long-term research.

4.2.4: Examples of materials R&D organisational approaches

According to information on corporate technology and R&D policy (e.g. Rolls-Royce, Nissan, Toshiba, Daimler-Benz, Alcoa, Audi, Toray, Siemens, ICI, mostly reviewed in the works of Kaounides (1992, 1994, 1995, 1997)), multinational corporations strongly involved in the MSE field tend to follow the mixed mode of R&D organisation because it combines greater levels of flexibility with opportunities to

[10] It follows that if the business units or the geographical divisions are technologically-specialised then there is a different division of R&D tasks.

optimise the design and the utilisation of the results of the corporate R&D portfolio. But the design of the details and the implementation of the model in each individual case largely depends upon the nature and the variance of the corporation's products and, probably, on the special characteristics of the involved materials.

The following analysis is based on information obtained from Daimler-Benz, (1994) an intensive, mostly structural materials user and ICI (1994/96) a large materials producer.

Daimler-Benz is an automotive, heavy machinery, transport equipment, aerospace and electronics producer and clearly an intensive materials user which provides particular emphasis in mastering advanced materials capabilities.

Taking the example of automotive and machinery, many materials grades and classes -mostly structural materials- and many other systems and parts are incorporated to the manufacturing of one, single, final product. The point is that all materials and all systems performance must be combined to provide one result: a competitive motor vehicle / machine etc. which is expected to have similar or identical performance all-around the world[11].

Obviously, this indicates that materials capabilities are crucial for the competitiveness of the final products and that such a sophisticated cumulative system of hundreds of parameters combining in one final result calls for a solid, well-defined, R&D policy. Therefore co-ordination of the R&D efforts in such a multi-dimensional problem is crucial while the influence of local market variations and specifications on structural components performance is rather limited.

Given the number of areas involved, Daimler-Benz has passed many of the R&D activities to their business units. But even though Daimler-Benz has passed many of their materials related R&D activities to materials suppliers, they have kept crucial R&D activities for structural and functional materials for in-house activities concentrated around their central research centre at the "Science City of Ulm", a Dm 270m investment. The central Daimler-Benz R&D laboratories have kept the responsibility of developing the long-run response of the company to future demands including the development of future technologies and materials which can find applications in many of the company's final products.

[11] Another similar example is that of Rolls-Royce aero-engines and heavy machinery. Here again, performance of *many*, mainly *structural*, materials has to produce one final result: an aero-engine for example.

As such, Daimler-Benz cannot afford to provide emphasis on decentralised ('peripheral') R&D portfolios because the risk of involving too many participants and parameters and losing focus or giving away secrets would be too high.

In addition, most materials used in motor vehicle manufacturing and machinery or aerospace manufacturing are structural materials. The radical improvement or the development of new technologies and products (at their initial stage at least) related to these materials would probably necessitate the combination of the full range of the company's competencies which (possibly) the business units do not have. Under this logic the aim of the company's divisions or business units is to "smooth" the edges of new technologies and products according to specific applications.

The *ICI* approach: ICI is one of the largest chemical companies in the world and it is mainly a materials producer. It produces more than 8,000 different products at over 200 locations in more than 30 countries all over the world. ICI operates upon five product-based business units, each with global and not just local presence: paints, films-acrylics-polyurethane, explosives, industrial chemicals and polymers including the Tioxide Group, and petrochemicals, catalysts and materials for personal care and detergent industries[12].

The major difference with Daimler-Benz is that while Daimler-Benz has to put many materials in one final product and mainly deals with structural materials, ICI has a vast number of materials which are end products *per se* and each competes in its own market with its special performance characteristics. Further, many products are functional materials (i.e. explosives, paints, films, chemicals etc.) which are heavily subjected to local specifications and performance variations (e.g. environmental condition for paints and adhesives, health and safety regulations for other products) and they are susceptible to extreme market pressures and demand changes.

Corporate technology strategy is under central control but the R&D strategy for each product or group of products has to be largely self-sufficient. Therefore the business units have a central role in forming and implementing the corporate R&D portfolio. Each ICI business unit is largely self-sufficient and has its own R&D resources which are up to a point business unit directed and funded. However, R&D managers in the business units must ensure that the R&D portfolio is sharply focused on the overall corporate business objectives and aims.

What is particularly interesting in this case is that ICI has re-opened central laboratories in 1996 (central laboratories were shut down in 1989). That is a very

[12] In 1998-1999 the company underwent major restructuring and divested or swapped many of these businesses.

strong indication that ICI recognised that there were many R&D issues with which the business units could not cope. ICI has adapted the globally decentralised R&D model giving a high degree of decision freedom to the local company's branches throughout the world, but now they re-state the role of the central unit as a point providing "depth" and cohesion to their efforts.

4.2.5: Materials Development Stages

Let us presume that a new material is to be developed following the needs emerging for a new demanding application and in simultaneous consideration of process and engineering parameters. As seen in chapter 2 there are two possible routes of action: create a totally new material or improve an existing one. In both cases the major and general R&D stages a material passes through, from theory to commercialisation, are the same. Emphasis intensity differs according to the choice of action or the special nature of the material. According to the Rolls-Royce approach[13] there are five development stages:

Stage I: given the basic fundamental performance requirements and specifications as inputs, the process begins with a search for materials solutions (including cost estimations) followed by results which will identify whether existing materials can be sufficiently improved or if it is absolutely necessary to create a new material from the beginning. At this stage there is a high degree of concurrent engineering of material and end product. Materials data are continuously fed into the design team (assisted by modern design tools and software) until a solution satisfies the need. Basic manufacturing parameters are also involved into the materials and design data. When agreement is reached, procedure, plan of action and funding sources are defined.

Stage II: In the case of "incremental" materials the group of potential materials must be reduced to one. Research is more of applied nature and less exploratory. Focus is given to materials performance and its relationship with its structure. Verification tests and parameters identification take place. Extended laboratory and theoretical work is involved. If theoretical understanding gaps exist they are covered before proceeding to the next stage (the material is still in the laboratory area). Collaborations with basic research institutions and universities can play an important role. Feed-back from "customers" and manufacturing never stops.

[13] See Kaounides 1994d and 1995d

In the case of developing a totally new material, the approach is different in this stage: extensive basic R&D takes place to match the findings of Stage I. Collaboration with research laboratories and universities is usually intensive. When the basic principles have been identified experimental construction of the material takes place in the lab. Basic tests are made to verify its fundamental requirements and specifications. During the entire procedure, potential production data are essential. After that, properties, structure and performance tests follow as in the previous case. In both cases S&P parameters are taken into account.

Stage III is intensive in identifying the suitability of the selected material for the given application. Applied working condition tests take place, and the fundamental working behaviour of the material is measured. Theoretical gaps may still exist and basic research still plays a role. This is more enhanced in the case of the NM. Stage III finishes with the end of the laboratory tests. The material is now formed into a real component in order to be tested as close as possible to working conditions. S&P data and parameters feed-back is particularly strong in this stage.

Stage IV involves the performance verification of the material according to anticipated expectations for the specific applications in working conditions before the component reaches the customer. Meanwhile, models of materials behaviour are developed including control documentation, guaranteed performance and setting, development, testing and manufacturing standards.

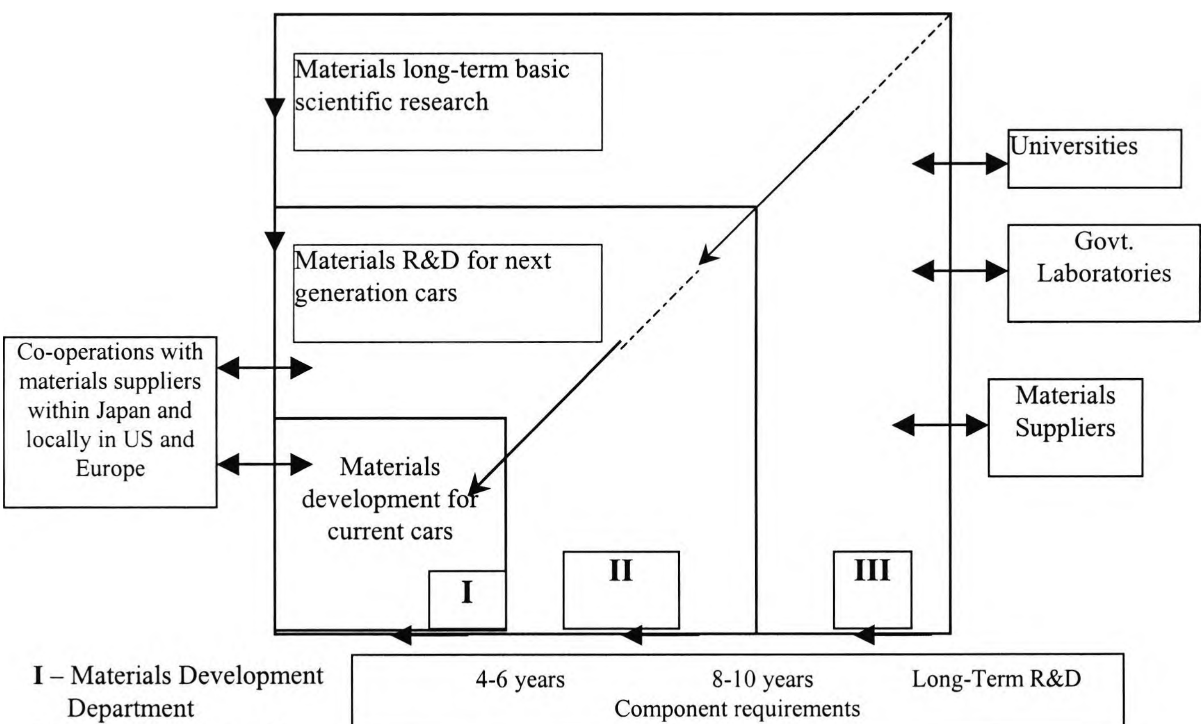
Stage V is the feed-back stage after the component reaches the customer. It contains provision of support and monitoring of the component in 100% real working conditions. Problems are recorded, failures, if any, are investigated and the information is fed back to the R&D stage (stages II & III) to support further and future design and development.

Stage I (specifications and decisions stage) is the most crucial from a strategic point of view, and the most demanding in user-producer communication and co-operation. Stages II (development of the material) and III (testing of the material –development of the component) include the incorporation of the main MSE capabilities and the company's core competencies. Stage IV (testing of the component) provides necessary reassurance and a compatible code of information exchange. Stage V (feed-back) is in fact the company's "probe" to the real world from which problems, their solutions and future needs can be identified.

The five stages model achieves to minimise cost and solve problems literally "on the spot", that is exactly at the time they are created. In addition, it is a very good example of the way in which materials development is integrated into SE of product and process development of engines and components in successive generation cycles (Kaounides 1995d).

4.2.6: Time based-frame work for materials R&D

The five materials development stages reflect the action path for providing solutions to one single application. When a company is committed to materials R&D there should be **three stages cutting through all materials classes** and activities with respect to time span. The best way perhaps to illustrate this argument is by studying Nissan's basic and applied R&D activities in Japan as illustrated by **Figure 4.3** and explained by **Box 4.4**[14].



I – Materials Development Department
II – Materials Research Laboratory
III – Materials Inter-disciplinary Scientific R&D.

Figure 4.3: Nissan's basic and applied R&D in Japan. Source: Kaounides 1995d.

[14] Extracted with permission from: Kaounides, (1995d): *'Advanced materials: Corporate strategies for competitive advantage*'. Management Report. The Financial Times, London

Even though materials are obtained from external sources, Nissan needs to know well each material. For example, Nissan conducts large R&D programmes in advanced and fine ceramics because it needs to understand the material before working on it, before it can set performance levels or ask suppliers to improve it. Additionally, Nissan is of the view that the more it knows about a material the more it can control the cost of this material. For these reasons, Nissan has in-house specialists in metals, ceramics, polymers and composites.

Nissan's basic and applied materials R&D activities can be conceptualised in a simplified schematic framework shown in Figure 4.3, which shows the successive stages through which materials research passes. Over time, new ideas and research results flow from Stage III to Stage II, where they are applied to R&D of next generation automobiles. Ideas and demonstrated research results in Stage II are then moved to Stage I where the former next generation concepts are now the current generation models developed over a four to six years period. As research results at a particular stage are "emptied" into the next stage, the former stage moves into new ideas and R&D programmes. In this way, work at each stage is constantly replenished and moves sequentially through to commercialisation.

Stage III: This stage involves the identification and articulation of future customer "dreams" which are used to set the appropriate parameters and targets and the relevant, long-term R&D goals. Here, there is constant interaction with universities, government laboratories, and materials suppliers, who in any case have on-going materials scientific research programmes. A key question asked by Nissan's researchers at this stage, is whether a particular concept or material actually works. Once this is demonstrated, then basic R&D flows to the subsequent stage (II), where the question becomes one of whether it can be applied to next generation cars.

Although basic research of a strategic nature can be demand-driven and directed to meet predicted future customer needs there is also a science-push element acting here. (For example the task might be a new coating with superior corrosion resistance).

Stage II: Given existing and identified requirements, the key considerations for scientists and engineers at this stages is how they can develop and apply materials technologies to improve next generation cars. Collaboration with suppliers becomes important from this stage onwards. (For example, a group of advanced coating materials and surface treatments are chosen to be applied on structural steels creating a new generation of coated steels).

Stage I: Engineers at this stage are concerned with meeting the materials requirements of current generations of models.(For example which coatings are best for which parts and for what local environment). Development work is carried out in Japan for the local market as well as for the overseas centres and markets. However, there is collaboration in materials development between the Nissan Technical Centre in Japan and the NETC in the UK. Both centres communicate with suppliers in order to develop current generation cars. At this stage, the Nissan European Technology Centre in Brussels, provides important information regarding requirements in the relevant markets, which must be met by the product development teams.

An essential part of the functioning of the Stages II and I is the holding of periodic meetings between Nissan and its materials and components suppliers during which future materials requirements are discussed, and suppliers can offer their own materials under development and point out their potential. Once suppliers are asked to develop a specific material, it takes up to three years to achieve the target performance.

Box 4.4: Nissan's materials R&D framework in Japan. (Source: Kaounides (1995) based on information provided by Nissan Co.)

According to Nissan, **every materials R&D portfolio** should include three distinctive but inter-related R&D stages: Stage I coincides with the near market R&D stage where the aim is to solve current manufacturing or product problems. Stage II corresponds to the applied / pre-competitive R&D stage aiming at the near future where scientific knowledge and engineering experience are brought together in order to formulate the next generation of products /services as a response to forecasted market demands. Stage III coincides with the fundamental / basic R&D stage which generates new knowledge and novel technologies while preparing the ground for distant future potential demands and needs. The 'model' describes the application of a 'third-generation' R&D applied to the materials case and developed to exhibit / provide its full potential.

In addition, Nissan clearly identifies that materials R&D strategies originating from market-pull forces alone contain the danger that no adequate consideration or weight is given to technology drivers[15].

If R&D efforts are driven exclusively from market-pull the potential to lose vision and develop core rigidities, resulting in emphasis given only to short-term and production process improvement is present and clear. R&D efforts, especially in the materials case, should be balanced between market-pull and technology-push because in the materials case the long-term effects are not easily visible and the involvement of materials is taken as given. If this point is overlooked and emphasis is not given to both short and long-term materials technologies, R&D activities will reach a dead - lock because the new materials capabilities necessary to support radically new products or services will not be available.

4.2.7: R&D as the strategic cohesion point of the corporation

According to the findings of previous sections, the corporation "responds" to its environment and adjusts to change and intensification of competition through the R&D department.

When it comes to materials technologies, R&D links all four elements of the materials tetrahedron and the three materials strategic levels (see Figure 1.1 and section 2.7).

However, a corporate R&D strategy for new or improved materials and processing technologies must be integrated with manufacturing technologies, both existing and under creation. This should be a solid part of the company's technology strategy which, in turn, must be fully integrated with the company's business strategies, that may be diversification or rejuvenation efforts pursued through technology fusion efforts or technology-based diversification or rejuvenation efforts.

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[15] Kaounides (1996) and Coombs (1994) also argue that R&D strategies originating from market-pull forces alone contain the danger that no adequate consideration or weight being given to technology drivers and to attempts to balance technology push and market pull in the company's strategy. A direct consequence could be the emphasis on short term and production process improvement rather than new product and processes and future technology development.

To achieve these complex tasks, materials, and in general corporate R&D, brings together strengths and inputs from manufacturing, scientific and technological developments, human resources, core competencies, financial planning, and business objectives and strategies. Technological information acquisition, reverse engineering, response to customers 'dreams', new product, services or technologies development, collaboration and communication between materials users and producers and other organisations (through which national policies in materials may be expressed or implemented), **all** go through R&D activities.

Conversely, R&D (and the way it is organised), reciprocally interacts with the organisational structure and the management practices of the corporation and frequently requires simultaneous availability of the full range of the corporate competencies to meet its targets.

Therefore, the special importance of R&D (materials R&D in particular) is that it provides a strong connecting link between the three corporate strategic levels (see Figure 3.5) while it simultaneously acts as a catalyst and melting point in the interaction between MSE strategies, technology strategies and business strategies. It would not be an exaggeration to suggest that R&D activities are a condensed reflection of the corporation's character, activities and strategic choices.

Finally, it has to be underlined that general ideas and practices about R&D policies are also applied to the MSE case. However, the requirements and special needs of the MSE field compel management to take specific R&D choices. Conversely, the experience gained from choices and R&D practices selected for materials technologies can be used as models for many other technological areas with similar requirements and restrictions.

4.3: Technology Alliances and Co-operation in Materials R&D

4.3.1: Why enter a technology based alliance in the 1990s?

According to Howarth (1994) "traditional" corporate reasons for entering an alliance are resources constraints, cost and risk reduction or elimination and market penetration. While the "traditional" reasons still hold strong[16], since the middle 1980s it is mainly technology constraints and competitive pressures tracing their origins to

[16] Essentially these forces can be seen as either a pressure of resource scarcity or the pressure of coercion (Howarth, 1994).

the new, technology-intensive, global environment which lead companies to form technological alliances. Corporations increasingly recognise that they can not afford to lose pace with even one technology stage without risking obsolescence not only in plant, equipment and suppliers but also in experience, products / services, "culture" and organisational skills. The threat is more obvious in cases where new technologies seem to become destined to substitute some of the firm's established core competencies (Millson et al. 1996).

Especially in the case of materials technologies, the formation of strategic technological alliances is a necessity for a number *of additional reasons* such as:

-- the technological complexity and multi-disciplinarity of the field *per se,*

-- the complexity of the involved tasks (due to the complex ways materials affect technological change and the technology and business strategies of the corporation),

-- the relatively high involved risks and costs in terms of resources, capital and time necessary for the development and commercialisation of results (long-term efforts are frequently necessary).

Indeed, evidence from the University of Limburg, Sweden and the US NRC (see **Table 4.2** and **Figure 4.4**), suggest that the formation of inter-firm technology-based alliances has become common practice in *all* three generic groups of technologies including advanced materials technologies. The most complex and numerous alliances are however, in the field of IT, where materials technologies also play an important role.

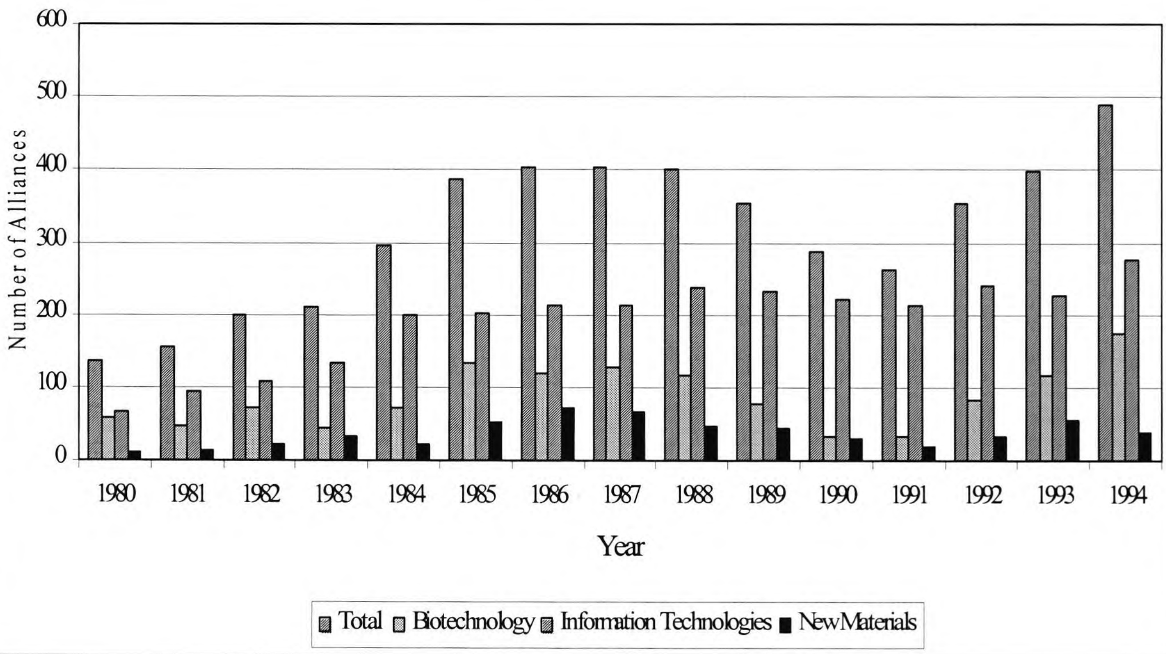
The formation of technological strategic alliances provides the firm with the benefits and the opportunities to combine technological assets, share the rising costs and risks of frontier R&D while minimising financial exposure, acquire complementary technologies, obtain speedy access to crucial technological and scientific expertise, and, in many cases achieve better focus when bringing resources to bear on innovation (Kaounides (1995d), Haynes (1994), Niosi (1993), Hagedoorn & Schakenraad (1990 and 1991)).

According to Lundvall (1992), the pre-1980s idea of self-sufficiency fades away as it becomes increasingly apparent that *learning by interaction* is today an equally important way for firms to *assimilate and complement* learning-by-doing or using.

Year	Total[17]	Biotechnology	Information Technologies	New Materials
1980	136	58	66	12
1981	156	46	95	15
1982	200	71	107	22
1983	210	45	133	32
1984	296	73	200	23
1985	386	132	201	53
1986	405	120	212	73
1987	404	126	212	66
1988	402	115	239	48
1989	355	78	233	44
1990	287	34	222	31
1991	264	34	212	18
1992	355	82	240	33
1993	399	117	226	56
1994	489	174	277	38

Table 4.2: Number of Strategic Technology Alliances by Selected Technology: (1980-1994). Source: J. Hagedoorn, Co-operative agreements and technology indicators data base IN Science and Engineering indicators, NRC 1996.

Figure 4.4: Number of Strategic Technology Alliances by Selected Technology: (1980-1994). Source: J.Hagedoorn, Co-operative agreements and technology indicators data base IN Science and Engineering indicators, NRC 1996.



[17] Includes international and intra-national technology agreements in biotechnology, information technology and new materials.

4.3.2: Materials Technologies and Technological Alliances

Basic characteristics. Hagedoorn and Schakenraad (1991), by employing the materials case as an illustration paradigm-case study, showed that networks of inter-firm technology co-operation *in new materials* are dominated by a number of leading multi-national companies.

The form and the specific motives behind each individual case of strategic technological alliance varies considerably[18]. However, Hagedoorn and Schakenraad (1990 & 1991) identified that the development and *sharing* of experience, new technologies and/or products based on new technologies is, in many cases, the central aim of the alliance, and, with respect to the three generic technology groups (including materials), *long-term strategic "positioning"* is a major alliance objective.

In addition, Bleeke and Ernst (1993), and Granstrand, Patel, and Pavitt (1997) pointed out that the most successful strategic alliances are formed among large (strong) **complementary equals** who remain strong during the entire duration of the alliance. According to Bleeke and Ernst (1993), these mutually beneficial relationships achieve a long-term strategic positioning which usually lasts *for more than seven years*.

In the materials case the formation of complementary materials technologies alliances usually takes place between large **materials producers** and intensive **final materials users.** Indeed, Niosi (1993) in his analysis of technological (R&D) collaborations in Canadian *advanced materials* industries demonstrated that there is a strong interaction between materials producers, final users, governmental laboratories and universities. The network of the inter-firm partnerships usually involves two or three major materials producers and final users, a number of highly specialised SMEs, and occasionally universities and / or governmental laboratories.

As is clearly indicated by the following case studies (see **Box 4.5**: The Siemens-Corning alliance **and Box 4.6**: The Alcoa-Audi alliance), advantages (such as gaining complementary assets, accelerated innovation, financing and R&D economies of scale among others) outnumbered the involved difficulties and bring some evidence against the usefulness of the transaction cost approach to the study of technical alliances in advanced materials. Both case studies share some common characteristics:

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[18] Hagedoorn & Schakenraad (1990) pointed out that from a large number of motives that could lead corporations to enter technological alliances, four motives appear to play a major role: the reduction of innovation period, the technological competence of partners, the prospect of monitoring technological opportunities and the possibility to find and enter new markets.

- They are dominated by materials technologies: the aims of the alliances were set after integrating the technological to business opportunities offered by exploitation of materials capabilities.
- Demonstrate how materials technologies can provide the basis of competitive advantage via technological, process and product innovations[19].
- Demonstrate a new mode of collaboration between both corporations and R&D portfolios with activities spanning from pre-competitive to near market stage.
- Collaborations of the Alcoa – Audi type provide materials producers with "secure" markets and "loyal" customers over a long period of time and materials final users with reliable and sophisticated materials suppliers.

Hence, we could conjecture that the *best practice in materials alliances* is the formation of selective alliances between materials users and producers. This type of alliance provides the opportunity to combine complementary skills, while, simultaneously, improving them through learning by interaction (see below).

The Alcoa-Audi strategic alliance

The long-term (12 years), materials-based technological collaboration between a major structural materials producer (Alcoa) and an intensive materials user (Audi) which led to the development and commercialisation of aluminium intensive vehicles makes an excellent example of materials complementary alliances. In the Alcoa-Audi collaboration Alcoa engineers were an active part of the Audi design team during the development of Audi 100. Materials, product design and manufacturing were integrated, with optimisation of materials structural design, of body frame and engine parts resulting in:

- Considerable weight savings with simultaneous increase in fuel efficiency and reduction of fuel consumption and environmental impact.
- Advantage with respect to similar steel designs in terms of safety, car stiffness and crash worthiness. At the same time German environmental regulations (among the strictest in EU) were satisfied while recycling become easier and cheaper.
- New production processing and assembly methods taking advantage of the formability of aluminium led to dramatic improvements in manufacturing simplicity and cost reduction: by taking advantage of materials based manufacturing and assembly opportunities, Audi managed[20] to replace the 400- 420 steel parts with 150 aluminium sheet, extrusions and castings with reject rates of aluminium parts less than 1% (same as steel despite the difficulties introduced by the use of aluminium).
- They set the frame and organisational plan for the development of next generation automobiles with scenarios including ideas for a cheap, aluminium frame and fully recyclable modular vehicle.

Box 4.6: The Alcoa-Audi Strategic Alliance (Source: Kaounides 1995).

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[19] A significant 'spill-over' effect of the Alcoa-Audi project was that it **stimulated the steel makers** to introduce new ultra light body steels and new weight-saving body-construction methods. According to British Steel, these were developed through a global consortium of more than 30 members, covering a wide range of technologies. This does not invalidate the Alcoa-Audi example, but it does reinforce the importance of reviewing more than one of new materials tailored to meet markets requirements as an integrated part of corporate technology and business strategies.

[20] Note, that similar actions applied in other vehicles using conventional materials provided similar complexity reduction results. The strength of the Audi case is the coupling of advanced with advanced processing and assembly methods.

The Siemens and Corning strategic alliance.

In this technology-based strategic alliance, Siemens, a corporation with considerable strengths and international presence in telecommunication technologies and in cables manufacturing/production technologies, and Corning, a corporation particularly strong in optical fibers and glass fibers technologies, combined their complementary technological skills in telecommunications and cables (final materials user) and glass technologies (materials producer) and created an independent company (Siecor) with leading position in the optical fiber cables industry. Both companies have contributed (but retained the control) a significant number of patents on which Siecor operates. Hence, the strategic and technological role of each partner has been secured and no partner wishes to exit the alliance.

Box 4.5: The strategic alliance between Siemens and Corning. Source: Bleeke and Ernst 1993.

The role of management. In strategic alliances of complementary equals (materials producers and materials final users in the quoted case) the role and the perceptions of management are of crucial importance (Bleeke and Ernst 1993). Good initial contracts can only secure a good start, they do not provide the key of success as the terms of the agreement (or many other factors of any nature) change significantly during the implementation of the project (especially in long-term projects as in the case of the two case studies above). The real challenge is the incorporation of change and flexibility and the preservation of balance among the partners. Niosi (1993) verified that management patterns in advanced materials alliances, show the predominance of flexible governance structures with characteristics including long-term agreements instead of joint ventures, two-member flexible partnerships and collective management. As Bleeke and Ernst (1993) put it, managers should focus their attention simultaneously on the future value of the each participant and the value of the alliance as a total.

According to Chelsom (1995) and Chelsom and Kaounides (1995) complex tasks of this type can be achieved only if management has adopted continuous improvement, SE and Kaizen management practices (designed to cope with change and to keep the balance during change) and only if the involved managers have ‘holistic’ management perceptions.

To take the argument one step further, if complementary materials alliances and co-operations take place between partners who operate under ‘holistic’ management perceptions and exercise LP and SE practices they will:

- Enable materials producers to provide complex AM systems to materials users,
- Enable both materials users and producers to forecast and prepare for future market needs ahead of end customers.

Kaizen and SE practices will also help these alliances to have clear objectives over the useful lifetime of the alliance.

4.3.3: Other forms of co-operation in materials R&D

Other types of inter-firm co-operations. Strategic alliances of complementary equals can involve all types of materials R&D (including competitive research) without risking a conflict of interest. However, alliances between corporations of similar nature (i.e. two materials users or two materials producers with potentially similar strategic aims and networks of customers/suppliers) can put extra strain on the management of the alliance as distribution of patents for tangible 'products' (or cross-licensing of patents already held) between the partners can be a very difficult and "sensitive" task. For a number of reasons, focus on materials (and other technologies) pre-competitive research (or basic research) provides a safer ground for collaboration:

i) In R&D alliances focused on the pre-competitive research stage costs and risks are shared while, simultaneously, participants can keep an eye on potential competitors and update their scientific domestic capabilities. *University and governmental laboratories* participation during this stage is increasingly becoming common practice.

ii) The results (generated knowledge and know-how) of pre-competitive research are not restricted to licensing and patents; they can be equally distributed among the alliance partners. In addition, it takes time for theoretical new knowledge before its applications are incorporated into new products and processes.

Collaborations between large corporations and SMEs. These schemes of co-operation are frequent but they are more in the form of collaborations rather than long-term alliances due to the tremendous difference of size and potential between the involved partners (Bleeke and Ernst 1993). They usually take the form of collaboration on niche applications involving S&P issues and problems where SMEs are highly specialised and have high levels of expertise. The entire production, manufacturing and supply chain of advanced composites for aerospace and other demanding applications has been developed on this model (Kottakis and Kaounides, 1997). On behalf of large aerospace corporations (e.g. Rolls - Royce), SMEs develop or have to offer advanced S&P methods and techniques for the production of limited volumes of parts or components.

Collaborations with universities and other research organisations. Universities and other research organisations such as government laboratories or research centres can contribute as collaboration partners in all materials R&D levels. Their traditional role is contributions during the basic and pre-competitive stages of research. However, according to the US NRC findings (1989) and the EU Brite/Euram evaluation reports both universities and research institutions (or governmental laboratories) increasingly tend to enter applied or even commercialisation stage research collaborations.

According to Hane (1991) there are four formal ways through which an organisation (e.g. a corporation or a public agency) can co-operate with a university, research institution or governmental laboratory[21]:

- By establishing a co-operative agreement (terms vary considerably),
- By requesting or sponsoring specific research to be conducted under contract (subjected to legislation),
- By donating funds to establish / create a chair, and,
- By dispatching researchers.

For EU universities and other research organisations there is an additional formal path:

- Participation in collective collaborative R&D programmes such as the Brite/Euram programmes or other EU collaborative schemes.

Hane's findings indicate that firms prefer to dispatch researchers or to set up contract agreements with a professor and his students for specific research, while Lastres (1994) pointed out that firms regularly regard as more important their informal contacts with universities and members of the academia than their formal agreements. Through these routes corporations are able to stay in touch and participate in global scientific and engineering frontiers and remain at the forefront of technological development.

4.4: Materials as Strategic Core Competency

Lei and Slocum (1992), and Prahald and Hamel (1990) pointed out that if a firm does not facilitate strategic alliances as "vehicles for learning" while simultaneously protecting itself from deskilling by managing its **core competencies**, the results could be tragic for the firm leading to dependence on former partners or suppliers.

[21] Governmental R&D subsidies and state funded research consortiums do not fall in this category.

Inadequate management or ignorance of what is core competency and what is not, is unacceptable in modern competitive conditions. The following paragraphs argue that this could not be more true in the case of materials.

The core competencies issue. According to Prahalad and Hamel, (1990), core competencies are the "collective learning" of the corporation and unlike physical assets, their value does not diminish with use but it is constantly increasing and becoming better and more valuable. Among others, core competencies enable corporations / firms to access chosen fields and markets and enable them to resist competitive imitation by involving a complex set of inter-dependent production skills and specific technologies. Klus (1993) pointed out that this competitive edge may depend on a patent, on a product or technology, or it could be a distribution, manufacturing or technology-intensity, knowledge-based system that is extremely difficult and expensive to duplicate. The competitive edge is often the result of knowing the business or the technology and /or its implementation better than any competitor so as to stay ahead of them with new products and improvements (Klus 1993). With respect to technology related core competencies, the competitive edge can also be the result of specialised manufacturing equipment, a unique process *per se*, (S&P in the case of materials) with or without patent protection, and unique product or services features due to technological superiority[22].

Within this framework, both in general terms (and in the materials field in particular), senior management faces the challenge to continuously keep balance between the benefits offered by an alliance and the risks of deskilling or giving away critical information to potential competitors. On this base, two issues emerge: to protect valuable technological information while interacting with others and to avoid gradual deskilling by sub-contracting core competencies[23].

On the make-or-buy decisions in R&D settings - whether technology is developed in-house or acquired from external sources (e.g., through licensing or R&D contracts) - Kurokawa (1997) showed that external technology acquisitions are more likely to be practised when the number of rivals expected to develop a similar product is greater (that is when base technologies are involved), and the needed technology is less related to a firm's core technology. He also concluded that external technology acquisitions reflect a technological problem-fixing attitude or aims to shorten development time, and thereby reap short-term profits (short-term strategy), while in-

[22] Klus also identified that competitive edge can be the result of non-technology factors such as distribution systems, raw materials or components supply systems, and services reputation. These can be complementary to technology – based core competencies.

[23] In other words is the typical make-or-buy balance dilemma in the company.

house developments aim to maximise long-term profits over the life of a given innovation or technology (long-term strategy).

It follows that to keep the balance, technologies and knowledge related to strategic core competencies must be identified and **kept** for in-house development or be protected as much as possible. Other necessary but not strategic activities can be left to sub-contracting or externally acquired[24]. In this way, management can remove the risk of giving away valuable information to the involved partners while benefiting from the alliance.

Materials and core competencies. Many multinational giants (i.e. Daimler-Benz, Nissan, Toshiba, Audi, Alcoa, Rolls-Royce, Nippon Steel) perceive as one of their fundamental core competencies either materials technologies and MSE skills *per se* or / and the ability *to use* MSE (the element of S&P in particular) to develop materials, products, processes and eventually markets.

In the materials case however, retaining balance between in-house and externally acquired technologies is a very delicate operation because materials have been acknowledged as fundamental core competencies, while successful integration into the firm's activities may require inputs from a wide range of interrelated technologies.

Therefore, a clear distinction has to be made: MSE technologies per se and/or the skills related to their use are core competencies **but not all** of them. Given the Dussage et. al. (1992) definition and analysis of the strategic importance of base, key and pacing technologies (see Annex 2.2), the distinction of which materials technologies are crucial for core competencies would be as follows:

Key materials technologies are those technologies which currently (and in the near future) provide technological competitive advantage and strategic differentiation to a given corporation. Capabilities in key materials technologies (including the skills to apply them) should be protected zealously while kept for in-house development. When they exhaust their forefront technological and commercial potential then they become available for trading.

Base materials technologies (which can be well-known, mature, outdated generations of key or emerging technologies) are widely available to many. If a corporation has problems in one of these technologies, or via diversification strategies is entering a new area where different base materials capabilities are necessary, it is recommended (Roussel et. al., 1991) to proceed in outsourcing or acquisition of these capabilities by

[24] There should be no confusion left between acquiring technological (and materials) capabilities through alliances or acquiring technological (and materials) capabilities through contracts or acquisition of other companies. By the acquisition of usually small to medium highly specialised companies, materials capabilities can be acquired externally but this is not an alliance.

alliances or sub-contracting. "Re-inventing the wheel" is not a recommended procedure as it will absorb resources for things readily available.

Finally, emerging or pacing materials technologies are the sources of future competitive advantage but they involve high risks and frequently demand multi-disciplinary approaches. Given the analysis in section 4.3, companies minimise cost and risks by developing or acquiring capabilities in these technologies by entering complementary alliances and collaborations.

S&P capabilities as core competencies. In addition to the above is the issue of identifying S&P related capabilities as strategic core competencies. According to Rolls- Royce, market differentiation in the future will not be based only on the ability to develop new materials but also on the ability to utilise in-house MSE strengths and materials understanding in order to develop integrated products and processes[25]. According to Rolls- Royce the ability to understand and apply materials can **not** be acquired externally. Hence, the company is focusing on two core competencies, namely understanding materials and being able to apply them to engine / component designs. In order to achieve this goal, the company has heavily invested in understanding and developing skills in all four materials elements providing particular emphasis on the in-house understanding of the S&P element. According to Rolls-Royce, these competencies are **not** for sharing at **any** cost even if mature technologies are involved.

4.5: Basic organisational core competencies for materials R&D

Successful design and delivery of complex materials (and other technologies) R&D programmes demands a number of internal organisational capabilities and competencies. These capabilities and competencies have a generic nature and they cannot usually be externally acquired (Gupta and Wilemon 1996). Therefore they have to be an internal corporate possession and fully incorporated in strategic business

[25] For example, structural materials mostly reflect and involve mature or well-explored technologies in the sense that they are widely distributed. If R&D results concern knowledge of the applied or commercial stage related to S&P improvements this knowledge can be directly adapted by many competitors, intensifying competition for the same products or applications. If steel maker (A) for example makes a significant improvement in steel production due to S&P innovations, and the know-how leaks out, immediately all steel producers will be potentially able to take advantage. On the other hand, if new materials knowledge is simultaneously developed with S&P capabilities (as in many functional materials cases), it becomes increasingly difficult to draw separation lines. Maybe this is the reason why alliances in, say, semiconductors are frequent in both emerging and key materials technologies.

and R&D considerations. According to Bell and Pavitt (1992), Milgrom and Roberts (1995), Kodama (1992), and Gupta and Wilemon (1996) it is imperative for corporations to include six related principles essential for technological and competitive advantage:

1. Internal abilities to build and deepen the in-house technological and knowledge base of the corporation through reverse engineering abilities and technology adaptation mechanisms.
2. Demand articulation and understanding of customer needs and monitoring market developments.
3. Intelligence gathering mechanisms (mechanisms to ensure monitoring of scientific and technological developments inside and outside the industry while collecting information for the activities of both visible and invisible competitors).
4. Good supporting technological skills cutting through all organisational and technological areas such as information technology and simulation and modelling capabilities.
5. The ability to form and manage long-term R&D ties and collaborations with a variety of companies or other organisations across many different industries.
6. Appropriate management philosophies and practices, that is abilities to manage complex and multiple R&D projects and cross - functional teams.

Reverse engineering and technological adaptation abilities are core competencies enabling the corporation to analyse, understand and finally absorb or imitate in-coming knowledge. Reverse engineering R&D activities must be included in the corporate R&D portfolio, while technological adaptation and reverse engineering mechanisms must be an integrated part of the corporate technology transfer mechanisms.

Demand articulation is the process of converting the customers vague demands into a set of R&D projects while providing directions and feed-back to business strategies. The task is more complicated than simply listening and responding to current and near future customer demands. As companies develop their skill at articulating demand they will also develop skills at technology competitiveness. But if R&D is only demand driven, companies may totally forget the technology-push effect which should remain as an active factor in the formation of the R&D portfolio. If the technology-push effect is not taken into account simultaneously with demand articulation, the company seriously risks in the long term to lose some key technological capabilities and face unpredictable challenges (Kaounides 1995).

Intelligence gathering and technology foresight mechanisms: technology intelligence gathering is gaining more and more strategic importance (especially in the materials area.) It provides the opportunity to keep in touch with the most recent scientific and technological developments, identify and evaluate emerging technologies, and obtain reliable feed-back necessary for updating in-house technologies and corporate R&D directions. Technology foresight has also been employed by world class firms in their effort to predict distant future market needs and emerging technological trends. Technology foresight and intelligence gathering focused on materials technologies provide the opportunity to fuse converging or even diverse fields (technology fusion) and to develop integrated products and processes R&D portfolios.

Information technology capabilities. A firm must possess computing, mathematical modelling and analytical techniques capabilities for both the R&D applications and as a general supporting tool for many other facilities and internal mechanisms (see also the importance of simulation and modelling skills for the MSE field in chapter 2).

Management philosophy. Organising and managing large and complex R&D projects in an effective and affordable way is essential. 'Holistic' management perceptions can prevent frictions, foresee difficulties and optimise the design and implementation of the R&D projects (Chelsom 1994, 1995). In addition, the mastering and implementation of Kaizen and SE management techniques provides significant advantages (Chelsom and Kaounides 1995). Companies with SE and Kaizen capabilities are able to develop products faster while they continuously improve them. Moreover, they have an advantage in developing materials technologies and integrate them into product development, while they can continuously improve both the way this integration is done and the product *per se*.

4.6: Implications for Industry

4.6.1: New emerging roles and opportunities for materials producers and users

The globalisation of markets, the application of Kaizen and SE management techniques, the developments in the MSE field and the changes in the characteristics of materials production redefine the role of both materials users and producers.

The materials users role. It is the final intensive materials users that define the materials properties and performance required for the development of new products.

However, these final users should also constantly seek demanding specifications and performance requirements from their customers. Ed McCraken, (1994) head of R&D of Silicon Graphics explains:

> "We look for customers who will demand computers 10 times faster and more effective in both calculating power and graphics capacity and at the same time are willing to explain how these new machines will be able to change their products or their production system. These are the customers we are looking for. On the contrary, when a customer requires cheaper computers from us we regard this customer as a bad customer because we have nothing to gain and we can not be further improved by a collaboration with them."

The example comes from the IT industry. However, the message is clear: low performance customer demands can initially provide easy profits but in the long-term, if they are the only customers, they can lead to technological capabilities erosion and decline.

According to Kodama, (1992) competitive advantage will come mainly *from the users -via performance demanding end applications-* but this cannot be achieved if not fully supported from reliable and sophisticated materials suppliers/producers. Indeed, since materials can be tailored to specific applications, final materials user industries play a crucial role in the improvement of incremental materials and the development of advanced or new materials. On the other hand, it is crucial for materials producers to form links with final users and participate in product and manufacturing process design from the very beginning. It should also be noted that a major constraint in the diffusion of advanced materials is the lack of repetitive, volume applications and markets.

The materials tailorability when combined with SE and LP practices provides the opportunity to tailor both components and materials systems to the assembler's or final user's specifications. Hence, materials producers would gain by collaborations with technologically demanding final materials users which will act as technological stimuli and will keep their technological and R&D capabilities strong and healthy. Conversely, technologically demanding user industries are a prerequisite for the improvement of incremental materials and the development of advanced and new materials.

Furthermore, if both materials producers and users are organisations using SE and Kaizen principles, then during the interaction between them, producers will develop capabilities enabling them to deliver complex advanced materials systems to users while simultaneously they "secure" markets and "loyal" customers over a long period of time.

The strength of the argument is clearly demonstrated by the complementary Aloca-Audi technological alliance (see Box 4.6). A large final materials user (Audi) contributes its experience in applying materials and seeks to gain understanding of materials production capabilities stimulating the development of advanced materials and processes. A large materials producer/supplier (Alcoa) contributes its experience in materials design, production, testing and evolution and seeks to integrate it with final stage materials processing and application capabilities as a contribution to the development of a superior final product.

4.6.2: From 'supply chains' to 'supply systems'

According to Chelsom[26] (1996), the 'traditional' supply chain stretches from

> "... holes in the ground or sea bed where ores or raw materials are extracted through refining of basic materials, the processing and forming of parts and components, the stages of sub-assembly, distribution, service and maintenance, and, eventually, disposal or recycling."

Along the way all manner of services and equipment are required. At every stage there are supplier/customer (user) relationships – internally between different functions within the organisation, and externally, between the organisation and its suppliers and customers.

In the materials case, the "traditional" supply chain includes large materials producer(s), a large number of "intermediates" (both large firms and highly specialised SMEs with particular strengths in niche technological applications) whose mission is to further process materials received by the primary producer(s) before selling them to the end materials users, equipment and machinery suppliers, and finally, end materials user(s) who impose the materials performance requirements. The "traditional" supply chain did not include much direct communication between the two ends of the chain. The "intermediates" acted both as technological and primary communication links, they received inputs from many materials producers and served many different materials users.

Rothwell (1994), Chelsom (1994, 1996), Kaounides (1995, 1996) and the case study of the Alcoa-Audi technological alliance suggest that while global competitive pressures provide the motive, the adaptation and implementation of SE practices, the opportunity to tailor materials to specific applications and the formation of complementary alliances between materials producers and users, provides the means

[26] See Chapter 2, pp. 15 in Payne, Chelsom and Reavill (1996). '*Management for Engineers*'. Wiley.

and the potential to transform and reshape the 'traditional' supply chain. The so-called 'original equipment manufactures', such as aircraft, ship, car or computer producers have to reach further down the supply chain for their concurrent engineering team partners. In similar ways, *materials* and services suppliers need to look further ahead to learn of new enabling technologies that will help them improve their materials and 'products', processes and performance. Increasingly competition takes places between groups and networks rather than individual firms. Small and large firms can be viewed as constituting innovation networks (or clusters) in which the dynamic complementarities between large and small firms are integrated and exploited (Autio and Laamanen 1995).

Chelsom (1996) and Clewer (1995) suggest that this drive of change entails a new concept of supplier management which recognises the constant and concurrent effects of these interdependencies: since all the members of the development team have to be involved concurrently, it is time to abandon the concept of a 'supply chain' which implies sequential links, and substitute the concept of the *supply system*. According to Chelsom (1996) and Chelsom and Kaounides (1995) management of *the supply system* (materials supply system in our case) is the one of the most important current keys to competitive advantage.

4.6.3: Materials Science and Engineering strategies and SMEs

When it comes to MSE strategies the company size is an important parameter. The complexity of tasks, the amount of required resources, the involved costs and risks point to the direction of large firms/corporations rather than SMEs. The flexibility of management and administration, however, can possibly point to the direction of SMEs rather than large firms. **Table 4.3**, as adopted by Rothwell (1983), suggests that in general terms, the advantages and disadvantages of large firms almost exactly mirror those of the SMEs. The advantages of high technology SMEs are essentially functional in nature - management and administration flexibility, speed and closeness to customers, innovative spirit- while the disadvantages are essentially resources-based: scarcity of capital, small market power, lack of professional management.

SMEs usually lack the resources or the management capabilities to develop complex R&D portfolios. On the other hand, large corporations have the ability either to raise funds internally or the credibility to secure them externally (e.g. loans, subsidies etc.).

SMEs are usually more innovative than large companies especially when innovation has to do with the *utilisation and employment of new materials or new processing* *techniques and* technologies[27]. Large firms/corporations appear rather slow in shifting out of old materials technologies into new ones.

Area	Small Firms Functional	Large Firms Resource Based
Marketing	Ability to react quickly to keep abreast of fast changing market requirements	Comprehensive distribution and servicing facilities. High degree of market power with existing products
Management	Lack of bureaucracy. Dynamic managers react quickly to take advantage of new opportunities	Professional managers able to control complex organisations. Can suffer from excessive bureaucracy
Internal communication	Efficient and informal internal communication networks. Fast response to internal problem solving	Internal communication sometimes cumbersome
Qualified technical manpower	Often unable to support a formal and sustained research and development activity	Can support the establishment of large research and development laboratories
External communication	Often lack the time and resources to identify and use external sources of information and expertise	Able to plug in to external sources of information and expertise. Can subcontract research and development projects to specialised organisations
Finance	Often have difficulty in attracting capital	Ability to effectively use a broad range of financing instruments and the financial market
Economics of scale and the systems approach	In some areas economies of scale can constitute a preventive barrier to entry. Inability to offer integrated product lines or systems	Ability to gain scale economies in production and marketing. Ability to maintain systemic products
Growth	Can experience difficulty in financing rapid growth. Entrepreneurial management can experience difficulty in coping with a growing organisation	Ability to finance expansion of production base. Ability to fund growth via diversification and acquisition
Patents	Can experience problems in coping with the patent system. Cannot afford to litigate	Ability to employ patent specialists. Can afford to litigate
Government Regulations	Often cannot cope with complex regulations. Limited chances of influencing the regulatory process.	Ability to fund legal services to cope with complex regulations. Often good chances of influencing the regulatory process.

Table 4.3: Dynamic complementarities between small and large firms in innovation. Source: Rothwell 1993.

This difference of characteristics creates opportunities for small and large firms to enter into co-operations but, as Bleeke and Ernst (1993) pointed out, if the dynamic balance of these complementary properties changes, the small firms can end up being acquired by the large firm. From the author's perspective, large firms in the MSE field regularly look for the opportunity to acquire SMEs, especially when the development of new materials and processes are concerned.

[27] The case of the high performance advanced composites required in low volumes for aerospace and other very demanding applications is a characteristic example of SME operating successfully in the materials field. In fact, the S&P technologies of advanced composites for very demanding applications have been developed mostly by SMEs or by co-operations with SMEs.

In fact, Hansen & Serin (1994) by using the Denmark plastics industry as a case study concluded that it is usually not large established firms that start new production on the basis of new materials. These firms wait until the market is ready and until the *entrepreneurs run into trouble.* On the same line, Madsen (1991) proved that in most cases established producers did not succeed in making the transition to new materials in relatively short time periods. Instead they continued with the existing material basis with new or left-over products. When conditions were ready they made their move and **acquired** the successful and innovative SMEs together with their market shares, know - how and skills which they integrated into their in-house skills and capabilities.

In addition, Autio (1994) argued that the most important impact of SMEs in high technology areas is achieved through the technology interactions between them and their environment. In the MSE field, this environment is usually controlled or is under the influence of large materials producers or users, so that SMEs need large companies to provide the very general operational frame and the general directions and points of references.

Therefore, a SME in the MSE field is likely to be more innovative in a narrow area and be more successful in a short period of time but is unlikely to be able to generate a new technology, or an entire group of new materials. So if a SME is to survive over a long period of time in the MSE field it should focus either on materials development and commercialisation, targeting niche markets and applications[28], or should develop competencies on the provision of high technology services to larger companies of the field. That is usually the development of a high level of S&P expertise for niche markets and specialised applications.

Finally, there is the case where the "SME" is not an independent firm but operates as an independent business unit (IBU) or a strategic business unit (SBU) of a large firm - usually a large materials producer. From the author's perspective when it comes to development and commercialisation of new materials a large company, via a number of IBUs or SBUs enters market niches or new fields of high potential. If the IBUs or SBUs start to grow, smoothing the ground and proving evidence that there is potential in the field, then the parent company follows by re-absorbing and transforming them. It is the method of the "guinea pig" where large firms use directly or indirectly SMEs as market, services and products "probes" and as collectors of knowledge and

[28] Typical examples are the bio-compatible materials for medical implants and devices. The over - specialisation requirements usually imposed by the needs of the individual person, the over - fragmentation of demand and the low volume annual output required make these materials unattractive for large firms and provide a fertile ground for SMEs to thrive.

experience. Under this scheme, an IBU or an SBU can develop their own R&D activities while keeping the parent company well-informed of the results[29].

4.7: Conclusions

** According to the sections above, industry has both the means and the experience to convert scientific and technological advance into "products" and services. Greater emphasis on the MSE field and in particular on the integration of MSE within the technology and business strategy of the corporation is necessary in order to maintain, improve and aggressively advance competitive positions in both domestic and international markets[30].

** Industries and individual corporations which employ Kaizen and SE management practices in order to build their in-house MSE capabilities according to their technology and business portfolio, and apply these capabilities to integrate the design of materials, products or components and the design of the manufacturing process, are well placed to take advantage of technological revolutions and have gained a significant competitive advantage over their competitors. In addition, Kaizen and SE management practices are the most suitable for the design and optimisation of materials strategies, corporate R&D portfolios, strategic alliances and the management of the complex interactions between the MSE field and the technological and business objectives of the corporation.

** R&D strategies are the most fundamental corner-stones of corporate technology strategies as they act as the primary connecting link and fusion point of science and engineering with product and process development. Materials R&D in particular, should be fully integrated in the corporation's R&D portfolio and its elements and directions should reflect needs of the technology and business strategy of the corporation. For this reason a third generation R&D management approach is required. Under this type of R&D management, materials R&D activities can simultaneously:

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[29] These arguments are mostly based on combined and critical analysis of literature sources and case studies. The gathering of statistical data in support of these arguments would be a fascinating area of further research.

[30] Under the condition that these efforts will not be interrupted. Especially for technological issues, an organisation cannot exit from a technology effort such as materials based technological change and expect to enter again after considerable time without suffering significant losses of skills, capabilities and core competencies

- Offer solutions for current problems,
- Prepare the ground or become the departure point for the 'materialisation' of emerging technologies and emerging business, and,
- Build or deepen the technological base of the corporation and increase its in-house skills of understanding, providing a significant basis for the development of strong in-house materials and other technological core competencies.

It has to be stressed that materials R&D portfolios have to place considerable emphasis not only in the improvement of incremental materials and development of new materials but on the simultaneous development of processing technologies (S&P) and standards. Materials R&D portfolios should also cover all three (basic/pre-competitive - applied – near market) R&D stages. These conditions can be met only if time and money spend in corporate R&D portfolios are seen as strategic investments and long-term, uninterrupted cash-flows are secured.

** Long-term MSE R&D efforts usually put a lot of strain on corporations because they entail high levels of cost, complexity and uncertainty. To tackle these problems long-term joint ventures or complementary technological alliances between materials users and producers are formed, leading to better materials and operational understanding, cost and risk reduction and improved manufacturing capabilities. New relations and roles between materials producers and users are emerging, transforming industrial structures and the materials supply chain. In addition, intelligent and well focused collaborations with universities, research institutions and governmental laboratories can enhance the effectiveness of materials R&D in industry.

** The identification and protection of core competencies is essential before a corporation enters a technology-based alliance. Materials and MSE related capabilities and the ability to understand and apply MSE principles (S&P in particular) for product, processes and even technology development are increasingly recognised as a fundamental core competency and as a main corporate strategic asset. However, much work remains to be done in fully understanding the issue of materials-related core competencies.

** The identification of some basic organisational competencies such as demand articulation, reverse engineering mechanisms, simulation and modelling capabilities and intelligence gathering are important tools in assistance to the corporation's R&D activities and core competency management efforts.

** While the above mainly concern large corporations, SMEs active in the MSE field should have better prospects if they harmonise and co-ordinate their materials and operational strategies along with the strategies of one or more major materials users or producers.

Finally, three additional points have to be underlined:

1. The concepts of operational effectiveness and business strategy are both essential to competitive advantage and superior performance which, after all, is the primary goal of any enterprise (or even national economy) **but** operational effectiveness is **not** and cannot substitute for strategy (Porter 1996). For example, management tools and manufacturing methods like Kaizen, and LP are necessary but not sufficient because they aim at maintaining competitiveness by maximising operational effectiveness over long-periods of time. They are crucial determinants of the successful development and delivery of a technology and business strategy but they can not substitute for them.

2. The above analysis applies to the MSE field and its direct environment, that is areas directly or indirectly but predominately affected by materials and materials technologies. Even though these concepts can be applied to other technological areas (e.g. biotechnology) the specific requirements and the implementation characteristics can vary considerably with the nature of variation being directly related to the characteristics of the underlining technologies (Oakey & Cooper 1991).

3. Industry, in general, cannot be responsible for the overall economic environment, the existing standards and supporting infrastructure and for the existence of a relevant education system[31], which will provide a stream of top quality human resources. Industry also cannot invest in large-scale basic research R&D programmes because the magnitudes involved are so massive, no corporation has the resources to deal with them. Further to that, issues of provision of "public goods" and of knowledge distribution infrastructure mechanisms arise. That is information centres, data banks, international patent protection and registration, and information networks for example.

It is in this context where government interaction must try to correct market "imperfections" *in the context of assisting* industry in the development of technologies, which might not be forthcoming if reliance is placed on the market forces alone. These points are identified and developed in Chapter 5.

[31] Industry, however, can surely take a part in the development of a "relevant" education system. For more see section 5.4.1.

CHAPTER 5: Materials Science and Engineering, the Role of the Government and Brief National Policy Examples

5.0: Introduction and chapter summary

Chapter 5 examines the national (governmental) response to the MSE challenges and the parameters shaping a national materials strategy. The first part of the chapter examines the question of whether it is justified for the government to take action in order to support the development of R&D infrastructure and the development of long-term enabling technologies (such as materials technologies) or leave these issues to the power of the market forces alone. Section 5.1 concludes that for the case of enabling and infrastructure technologies like the materials technologies, and particularly for the case of small economies competing in global conditions, the State should take an active role in supporting and promoting the development and diffusion of enabling and emerging technologies.

Section 5.2 examines the role of the government in shaping and implementing a national materials strategy. The role of the government can be summarised under the three basic principles of:

- Identifying areas of importance and indicating directions,
- Providing a favourable environment for the incubation, development and diffusion of these technologies and,
- Organise and supervising R&D and other activities (such as large scale national R&D projects) in these directions.

Section 5.3 provides a brief analysis of infrastructure issues (focusing on education, standards and research organisation issues in particular) and their importance for materials technologies. Chapter 5 concludes with a brief overview of characteristic cases of national materials strategies, aiming to focus on the strengths of each case and provide paradigms of the best aspects/elements of each reviewed case. The "codes of practice" covering the third level of materials strategies (the national level) are established in this chapter. A synthesis of examples applied in both small and large countries provide the necessary elements for the selection of national materials priorities and their efficient support.

5.1: The role of the government in the development, diffusion and commercialisation of technology

The previous chapters and sections identified that improved and advanced materials and their commercial applications are set to become a crucial determinant of the competitiveness of firms and entire branches of industries, hence industrial growth, trade, employment and national prosperity.

Therefore, the critical question is whether the government can (or should) become a major determinant of materials technology development and commercialisation or not.

International experience shows that many governments around the world are no longer in any doubt about the importance of externalities that are created through the development and applications of AM and other generic and/or emerging technologies. Consequently, an increasing number of industrialised or newly industrialising economies (NIE's) have taken steps to develop strong national materials strategies (including basic research and materials R&D programs) to ensure technological advance and economic competitiveness.

The following paragraphs provide a brief overview of the economic rationale for government intervention in shaping and implementing a national technology and materials strategy.

5.1.1: The economic rationale for government intervention: Market imperfections and the dynamics of technological advance

Governments generally turn to economic theory in order to justify their action to support their science and technology (and materials) policies. The economic rationale for industrial and technology policy is based upon the arguments of the traditional economic theory which examines the conditions for and the properties of a perfect competitive equilibrium as expressed by the Pareto Efficiency criterion and the Pareto Optimality conditions (see **Box 5.1**) which are seen as necessary for maximising social welfare in a market economy. Under certain conditions a perfectly competitive economy will tend to equilibrium and a perfectly competitive equilibrium is Pareto Efficient.

However, many authors (e.g. Clarke (1985), Stoneman (1987), Hay and Morris (1991)) argue that in real economies these conditions do not prevail: uncertainty, risk, externalities, public goods, increasing returns, technological effects and dynamics, information asymmetries, 'moral hazard' create considerable imperfections and market distortions. If an allocation of resources is not Pareto - Efficient, then the economy is out of Pareto optimal equilibrium and we have market failure.

Pareto Efficiency: An allocation of resources is Pareto Efficient if there is no other feasible allocation (of resources) which would at least make one individual strictly better-off and everyone else at least as well off as before. There may be many different Pareto - Efficient allocations of resources.

Conditions for Pareto Efficiency

1. Producers maximise profits, consumers maximise utility.
2. Perfect competition prevails in all markets and there is no market power: producers and consumers cannot affect market price individually.
3. Perfect information about current prices and quantities and no uncertainty about the future (or perfectly competitive future markets for all goods and a market for shifting risks).
4. Prices are formed such that all markets are simultaneously in equilibrium.
5. There are no "externalities", no increasing returns, no public goods, no indivisibilities.

Box 5.1: Pareto Efficiency and Conditions for Pareto Efficiency (Adapted by Jones (1985): Principles of Resources Allocation)

The justification for governmental action is that sole reliance on market forces[1] will probably fail to produce the desired allocation of resources and outcomes (optimise social welfare). As such, the authorities try to correct for market imperfections and particularly the market's innate defects and distortions. Market failure and the consequent misallocation of resources provides theoretical justification for corrective government intervention in the case of the formation and implementation of national science/technology policies[2].

The difficult part for the government is to provide adequate rationale and to identify and demonstrate that resources, if left to market forces alone, are shifting too slowly in high technology sectors critical for the economy, or that the transformation of traditional declining sectors is too slow. The following considerations provide evidence of market failure and according to the reviewed literature supply the necessary economic rationale for national technology strategies.

[1] According to the traditional economic theories only economic factors affect welfare, and these can be aggregated into consumption (Dasgupta and Stoneman 1987).

[2] An authoritative analysis for the economic rationale as well as objectives of government intervention in the process of scientific and technological advance is provided by Dasgupta and Stoneman (1987) in '*Economic Policy and Technological performance*'. Cambridge University Press.

5.1.2: The issue of wealth distribution and resource allocation in knowledge-based economies

In the new, global, information and technology-intensive business environment wealth is (mainly) derived from technological innovation (Ayres 1988). Corporate and national wealth is getting less and less synonymous with capital but increasingly with ownership of know-how and information (Ayres 1988, OECD 1989 and 1992, Rosenberg et. al. 1992). Indeed, improvements over the past 30 years in statistical data, analysis, and related theory on the knowledge-based economy have confirmed the importance of technical change for productivity, trade and employment, investment, the structure of industry and, most importantly, its impact on the increase of economic welfare and national economic performance (Arrow 1962, Clarke 1985, Morris & Stout 1985, Stoneman 1987, OECD 1991 and 1992, Tyson 1992, Metcalf 1995, Kaounides 1995, Pavitt 1996).

The dynamics of technological advance and knowledge-based economies provide a strong basis for questioning of the Pareto optimality conditions, which are seen as necessary for maximising social welfare in traditional economic theory.

During the industrial era the State could more or less intervene in the economy and control the capital and wealth distribution. In the knowledge-based economy, if wealth equals knowledge and technology intensity, and not just raw materials or economic/ financial capabilities, the government can only promote the knowledge generation towards a selected direction, but not re-distribute the gained knowledge. While barriers for products and industries are falling, barriers of knowledge (e.g. patents, copyrights) are strengthened, increasing information asymmetries and hence market imperfections (Clarke 1985, Hay and Morris 1991). Moreover, mainstream economic theory which accepts the equal value principle[3] and does not recognise the cumulative gains of technological trajectories included in a technological investment or high technology industry may be falling out of place[4].

[3] Equal value principal: An industry which produces frozen food and has a turn over of say $100 m, has equal value and gravity with a semiconductors industry of the same turn over ($100 m). For example: why should we produce or invest in semiconductors when we can get the same money from potato chips?.

[4] A high value product will provide maximum benefit to the producing industry or country by its high added-value, its utility and by the patents and standards control opportunity it offers. Only when price and profit margins start falling will this old and exploited knowledge be available for sale or even totally replaced. There are strong indications that some exploited technologies are not sold at all. When they have been sufficiently exploited they are shut down altogether. This is because if sold, they can create future potential competitors because the knowledge they contain is the basis for a set of new technologies.

Within the framework of the knowledge-based economy, a number of cases of potential resource misallocation emerge:

The development and diffusion of emerging and generic technologies [5]. Given that in the knowledge-based economy wealth and technology are becoming inseparable, the development and diffusion of a critical mass of skills and capabilities in critical groups of both generic and emerging technologies is of strategic importance[6]. The complex nature of many emerging technologies (e.g. materials and information technologies in particular) the long-term and mostly "invisible" (in financial terms) effect on other technologies and the vast resources necessary for their development and diffusion make it difficult for individual firms to justify and sustain the required R&D investment expenditures over long periods of time. For these reasons, industry may regard them as not feasible and thereby reject them, putting its future competitive position (and hence national wealth) in jeopardy.

If the private sector is unable or unwilling to dedicate sufficient resources, the government should be concerned that the appropriate conditions be met whereby industry acquires technological leadership, taking advantage of the opportunities offered by these technologies by initiating activities for their nurture and diffusion into the industrial base in areas where they are expected to make their primary beneficial contributions.

Support for basic research. Fundamental (basic) and pre-competitive research provides a typical example of market failure (leading to resource misallocation). According to Arrow (1962a,b) and Hay and Morris (1991), basic research, that is the creation of new knowledge, is related to problems of risk, in-appropriability (hence investment cost justification), 'moral hazard', indivisibility and information asymmetry issues and/or protection of information issues.

The remoteness of basic research from the market-place, its uncertain results and the difficulties and risks associated with commercialisation discourage private investment. Moreover, returns from basic research are frequently invisible because they cannot be accurately measured. Therefore, there are dangers diminishing the economic usefulness of basic research which continues to rely in the provision of skills (in many cases tacit skills) rather than codified and applicable information of immediate returns (Hall 1991, Pavitt 1991). In addition, basic research generates new

[5] For definitions see Annex 2.2.

[6] See '*Technology and the Wealth of Nations*' by Rosenberg, Landau and Mowery (1992) and the '*Technology and the Future for Europe*' by Freeman et. Al. (1990).

knowledge, which cannot be easily patented or protected (Clarke 1985). A large proportion of the benefits of a company's investment would leak easily away[7].

For these reasons firms cannot fully appropriate the gains of their basic research efforts, which may be appropriated by other organisations. Hence, they tend to under-invest in basic research in relation to socially desirable outcomes (Hay and Morris 1991). All these reasons come into conflict with the conditions for Pareto Efficiency (see Box 5.1), leading to market failure, misallocation of resources and less than optimal social welfare outcomes.

Therefore, basic research **emerges as "public good[8]"**, publicly funded basic research is an indispensable source of useful knowledge and skills for business, and, governments have sufficient rationale to make up for the lack of initiative by industry and provide funding or resources for basic research (e.g. at universities and State laboratories) or support a web of national research organisations in order to correct for this resources misallocation (Pavitt 1991 and 1996a,b).

Further, recent innovation studies confirm that continuous technical change in both manufacturing and business firms in modern society would require the development in close proximity of publicly funded basic research and **associated infrastructure** and **training** (Pavitt 1996). These points are particularly important in the case of materials and other similar fields where basic research is very important, while results are remote and uncertain.

Research infrastructure, standards, measurement techniques and education as "public goods":

Public goods are essential elements for the welfare of a nation which due to scale and complexity no "individual" has the means or the motive and interest to invest and provide. Therefore, the government has the duty to correct this market imperfection and provide several 'public goods' such as national security, education, testing and measuring mechanisms etc (Tassey 1992, Link and Tassey 1993, Tyson 1992, Prabhakar 1995).

According to (Tassey 1992), in a knowledge-based economy there are three areas where government intervention can increasingly correct for market failure: early phase R&D (see above), commercialisation of new technologies and market development. The provision of research infrastructure (networks, diffusion mechanisms, public research organisations), education, and especially of standards and measurement

[7] This would happen because researchers have two essential and economically efficient freedoms: they can publish their findings and change jobs (Pavitt 1996).

[8] As Pavitt (1996) put it, "...without State funding for fundamental research life would rapidly revert to being nasty, brutish, and short".

technologies is essential for R&D activities and the development and diffusion of **all** high technologies in the next century (Tassey 1992, Prabhakar 1995, Kaounides 1995). The onset of the biotechnology, information and materials revolutions and the global market place are demanding an increasingly diverse array of infrastructure technologies which no private source can provide (e.g. synchrotron radiation facilities).

For all the reasons above, a national science and technology policy may correct the market imperfections and lead to a Pareto - Efficiency improvement and an increase in welfare.

Of course there are some (e.g. Krugman and Obstfeld 1991, Boskin 1991, Boskin and Lau 1992) who argue against the justifications above, pointing out that there are serious difficulties in implementing the theoretical spill-over arguments for the benefits of an industrial and technology policy, while many of the imperfections mentioned above have been mainly created by long established existing governmental intervention. On the contrary many others (e.g. Tyson 1992, Tassey 1992 and 1996, Pavitt (1971, 1991, 1996), Freeman 1982, Stoneman and Dasgupta 1987, Metcalfe 1995) insist that these market imperfections have an incrementally negative effect on those who do not address them properly, while having a positive incremental effect to national economies who do. Examples of national technology policies coming from the Far East and other Western nations[9] corroborate the argument that governments of both large and small nations do and should take active roles in correcting market failure and securing national welfare by designing and implementing national science, industrial and technology policies and strategies.

5.2: National Materials strategies and the role of the government

According to the findings of the previous section, a role for the government does exist for both the case of materials science and technology and for technology development and commercialisation in general. This role can comprise the identification, formation and implementation of a national materials strategy as an integrated part of the overall national science/technology strategy and the national industrial policy. In that case the role of the government is three-fold:

I - To identify directions and design a materials strategy according to national needs, (industrial and technological needs) characteristics and selected visions and to integrate it into the overall science and technology policies of the nation.

[9] See Nelson (1993): '*National Innovation Systems: A Comparative analysis*.' Oxford University Press.

II - To provide or promote the development of suitable mechanisms and the requisite financial, business and infrastructure environment for supporting the development of the selected materials strategies.

III - To stimulate, organise, supervise and regulate the necessary activities and institutional responses to the MR challenge.

These three aspects of government's role are described below.

I - *Identify directions and shape a national materials strategy.*

Usually, both within a general framework and in the materials case, the first action taken by governments is to identify the current and future needs of the national industry - services sector included - and economy. The second step is to set, in co-operation with industry and other institutions and organisations, the priorities of the national materials strategy designed to meet the aims and targets of the national technology and industrial policies.

The development and the pursuit of national materials strategies provide significant services to the national industry and economy by identifying current and future technological trends and pointers to future technological and commercial opportunities or activities. This is the primary role of the technology foresight programmes carried out at regular time intervals by many countries in the world[10].

Given that some generic groups of technologies are extremely diverse (as in the materials case) identifying and pursuing priorities is particularly essential for economies with weak industrial structure and capabilities which cannot afford to promote a wide portfolio of activities[11].

II - *Providing and promoting a favourable environment for the development and diffusion of selected materials technologies and the national materials priorities.*

Apart from shaping a national materials strategy and identifying priorities, a number of peripheral and more general actions *(horizontal measures)* in areas relevant to materials technologies must pro-actively or simultaneously take place. The aim is to

[10] Typical examples are the emerging technologies lists published by the US DOC, DOD and NRC, the UK Technology Foresight activities, the French national technologies lists, and many similar examples coming from Japan, Korea, the Far East, Germany, Brazil, small European countries (e.g. Holland, Portugal), Canada and many others.

[11] Just as a fund manager diversifies risk through a large portfolio of investments (expecting some failures) a country should pursue as many emerging technologies as the characteristics and scale of the national economy allow to assure maximum flexibility aiming to capture the economic benefits from those technologies which will eventually prove successful in domestic and international markets. A wide - front approach may be appropriate for large economies but may be less relevant to smaller economies which may have to concentrate on a narrower set of technologies. Especially for small economies or NIEs it is crucial to target and develop generic skills and accordingly select specific technologies and materials priorities

provide *a favourable environment* (both economic, financial and technical) and the appropriate mechanisms for the development and implementation of materials (and other) technologies. The employed horizontal measures can either be applied so as to support indiscriminately all scientific and technological fields or they can be tailored (or ex-post directed or modified) to support specific technological fields such as the MSE field. Within this framework, the government initiatives can be summarised into two major groups of activities:

Activities supporting the development of national research infrastructure[12]

i) Support and funding of basic (pre-competitive) research. Examples include the support of university research on the basis of criteria of excellence (e.g. Belgium, USA) or by supporting a web of national or federal laboratories not totally oriented to defence related research by provision of credits and grants for materials related activities. Other measures include the design, implementation and subsidisation of collaborative pre-competitive or applied research schemes (e.g. the EU R&D collaborative schemes).

ii) Provision and improvement of *the national research and technology infrastructure*. Efficiency in the use of technology depends on the availability and accessibility of generic know - how, and facilities such as availability of methods, physical R&D infrastructure (e.g. research institutions and instrumentation), standards, databases and standardisation mechanisms (Tassey 1992). Additionally, education and training policies, research and technology national laboratories and research networks including universities are crucial aspects of a national research infrastructure.

iii) The provision of mechanisms for R&D collaborations and for the formation of industrial networks and R&D clusters. The government can take the initiative to bring together universities and industries and act as a catalyst to the formation of alliances and collaborative schemes (e.g. the LINK scheme in the UK).

iv) The creation and support of diffusion mechanisms dedicated to the promotion of technological innovation through the diffusion of research results and scientific / technological information. Further, the provision of assistance and information to potential participants with respect to the existence, the potential and the opportunities of national and international collaborative R&D projects (e.g. the Brite/Euram programmes) is also as important as the projects. Technological consultation, information and documentation centres and high speed communication networks are a government / industry priority in many Western and Far East countries.

[12] See also '*Special Issue on Public/Private Partnershisps in Science and Technology*'. STI Review, No 23, OECD (1994).

Activities creating a favourable economic and business environment

i) Government procurement policies in the form *of R&D contracts.* In this case materials oriented research organisations or industries benefit from large scale collaborative R&D programmes targeting specific applications or fields.

ii) Government procurement policies in the form of '*market securitisation*'. In this case the government acts as contractor or purchaser of large scale construction or high-technology development programmes and services. The sales guaranteed by government purchases assist innovation efforts in high technology fields (e.g. France, USA - military applications) and support "infant industries" during their uncertain first steps (e.g. South Korea, Japan) either by securing markets or by enabling firms to learn and gain experience in volume production. These selective purchases can also work as a means to rejuvenate existing industrial sectors by providing a sales guarantee until the initial transformation / rejuvenation investment pays off. Even though this practice can be applied in any technological field, it is particularly effective in supporting the development or maintenance of materials skills and competencies.

iii) "Infant industries" and "National champions". Another argument in support of government's role in materials and other technologies is based upon the domestic generation or protection of essential elements and skills of strategically important groups of technologies (Krugman and Obstfeld 1995).

With respect to the former (creation of domestic skills) some countries (e.g. South Korea, France, Taiwan) apply the "infant industries" approach through the provision of governmental procurements or markets securitisation to weak and nascent industrial sectors which are regarded as crucial by policy makers but remain unnoticed or endangered by market forces. With respect to the latter (protection of existing domestic skills) government action may, but not necessarily, take the form of "picking winners" by the provision of support to a group of pre-selected "national champions[13]".

These policies are harmonised with efforts with which countries wish to transform their economies or the nature of their economies (Nelson (1993), OECD (1995), Shin & Kim 1994). Some economies based to a large extent on agricultural or natural resources products are trying to promote industrial structures capitalising on high value added products by using the 'infant industries' or the 'national champions' method on a wider basis than industrialised economies. Further, small countries tend

[13] Note that this policy is a hotly debated area in economics.

to use the "infant industry" and the ‘national champions’ concept more frequently than large countries.

iv) Export policies. Export policies can have dual action:

a) Promoting and supporting exports or assisting in the creation of an international trade web. We observe that in many countries entire industrial sectors have been developed with an internal market orientation and philosophy. These industries lack experience in penetrating foreign markets and in establishing distribution and promotion networks. As a result this type of firms / industries faces severe problems when trying to develop an export strategy. Government can provide much counselling, financial initiatives, and organisational assistance (network provision and solving international legal issues through political negotiations with governments, or moving into international agreements such as trade agreements, or using national diplomacy as a means of leverage in order to ensure or create new markets) in this area.

b) By giving economic and financial bonuses (e.g. tax incentives, low interest long term loans) to companies which significantly contribute with their exports to the country's income.

v) Promote private sector's R&D activities by setting a favourable financial and economic environment using incentives such as tax policies, promotion of patient capital and investment policies, and others. Tax incentives for example, have proved their value because they are not discriminatory and have an automatic effect. Varying in their form, tax exception systems for R&D exist in many countries (i.e. US, Ireland, Australia, Canada, South Korea and others). These incentives heavily involve the national system of financing innovation and they are discussed in more detail in chapter 6. A question arises in the current technological and global networking of NSIs as to whether tax incentives of R&D are the best or most effective means to promote national innovation.

III - *Supervise and regulate R&D initiatives and R&D supporting activities*

This set of measures involves the formation and provision of various institutional mechanisms necessary for the implementation, supervision and evaluation of the national technology and materials policy objectives. Some of them are:

i) Co-ordination and supervision mechanisms. Supervision of governmental initiatives in large collaborative R&D schemes is as essential as the projects *per se*. The continuous monitoring and evaluation of directly allocated financial support for R&D or other related activities through national science/technology funding bodies provide considerable assurance for the good use of the allocated resources and for the achievement of the final task. In Germany and Japan for example, there are special agencies committed to the co-ordination and supervision of common industrial efforts of both national and international character.

ii) *Regulation mechanisms:* New products require evaluations of their impact on health, safety and the environment that are often lengthy and costly. In the case of advanced or new materials this is a critical parameter as lack of standardisation and evaluation regulations can considerably delay their introduction in commercial applications. In international markets the problem is more intense because there are large differences in regulatory requirements between countries. Regulations can also take the form of entry barriers against poor quality materials and structures.

iii) *Intellectual property protection:* businesses in high technology and in materials technologies in particular, rely on intellectual property protection to capture the economic benefits from innovation. Intellectual property rights, and their effective protection and enforcement, are essential if firms are to invest in new technologies such as advanced materials, biotechnologies or advanced electronics. Patents, copyright and trade marks in advanced materials, biotechnology, information technologies and software were the main subject of the Trade Related Intellectual Property (TRIP's) agreement under the GATT '94 and the WTO '95 (see UNCTAD 1994).

5.3: Materials Science and Engineering and infrastructure issues

Infrastructure can be referred to national, industrial sector, firm, or department and laboratory level. The following section refers to infrastructure issues at the national level.

The term infrastructure for science and technology has a dual nature which can be static or dynamic: static infrastructure includes equipment, instruments, plants, laboratories, research sites, installed power and telecommunication networks and the existing group of testing and measurement and evaluation methodologies, standards, data and information collections and archives. Dynamic infrastructure involves human resources, educational system, collaboration networks, R&D organisations and investment schemes, and co-ordination and decision making bodies.

Infrastructure strategies and their results are not directly embodied in a product in the same way as specific technologies and their impact is not so obvious (Tassey 1992, 1996). However, investing in infrastructure is of significant importance because there are only two components in a country's economy that cannot be relocated easily or in large numbers - its people and their knowledge-based skills, experience and learning capabilities (dynamic infrastructure) and its public infrastructure such as roads, communication and energy technologies and educational and research institutions (static/dynamic infrastructure). Investing in things that cannot easily move is, in the long-run, the most fruitful economic choice (Reich 1992). At the same time, high quality infrastructure can affect (and attract) foreign direct investment, with R&D labs, researchers and design centres contributing in a dynamic process to the local economy (Kaounides 1999a,b).

With respect to AM technologies and high technology in general, there are three most influential infrastructure areas: education policies; availability of standards, data bases and information archives; and research supporting facilities (institutions, organisations and research networks dedicated to pre-competitive or applied research).

5.3.1: Advanced Materials and Education

The term human capital refers not only to existing abilities but also to the capacity of the labour force to adopt new techniques and technologies. The economy's ability to create and incorporate new technology and knowledge critically depends on education and technology transfer via education[14] (OECD 1996a,b,c). International comparisons confirm that countries which have highest rates of productivity and technological advancement tend to be those with high standards of education and training.

With respect to the MSE field two education issues arise: the first addresses educational needs strictly related to the scientific/technological nature of the field and the second addresses education issues necessary for the successful management of the complex interaction of the MSE field with corporate and national technology and business strategies.

<u>MSE and Academic Education Issues</u>

Two major reports coming from the OECD (1990) and the US NRC (1989) and a number of later studies (e.g. Stokes 1990, Smallman 1990, UK DTI 1995) recognised MSE education and training issues as one of the most fundamental corner stones for successful implementation and integration of materials technologies into economic, business and societal needs. They also stressed the need for most OECD member countries, and the US in particular, to reform their educational system in the MSE

[14] People studying or training abroad and returning to their origins.

field and harmonise the university and training curricula to the modern MSE needs. The following issues received particular attention.

1. Materials scientists and engineers availability: The first major observation is that the MSE field is suffering from a relative stasis or even decrease in student enrolments at both undergraduate and postgraduate levels, leading to a potential deficit of materials scientists and engineers in the US and EU by the turn of the century (NRC 1989, USNSF 1994 and 1996). Economic reasons, reasons of insufficient social recognition[15] and lack of public awareness regarding the role and importance of materials throughout all educational levels (even among engineering circles) were identified as the basic origins of the problem. However, Japanese companies created new materials departments in the 1980s in order to attract the best and brightest scientists and engineers from Tokyo and other universities.

2. S&P weaknesses: Following the trend above the most brilliant and ambitious minds rarely follow a materials engineering career. Consequently, MSE is mainly covered by scientists (mainly physics or chemistry) and less by engineering professions, thus creating a tendency to have a persisting maladjustment between the demand and the supply of skills (Stokes 1990). The lack of good materials engineers and the strong science background of those in materials fields results in strengths in properties and structure and composition but weakness in S&P and performance which are the connecting link of MSE with technical change, industry and national systems of innovation. In the NRC report (1989) the S&P area has been identified as the area suffering the most from weaknesses and deficiencies originating in the education system.

3. Availability of financial resources: Materials departments and laboratories are the second most expensive academic/research institutions (after medicine) to be equipped and operate. To fully equip a materials department and cover the inventory cost, several dozens of millions of dollars are required. To update it, an annual expenditure of 10% to 15% of the initial investment is required (NRC 1989). To meet these costs academic departments cannot depend on government support and teaching grants only. Collaborations with industry or international research institutions and programmes can bring capital and new instrumentation which become the property of the individual academic departments. This is not something new, but if this policy is important for most departments it is a matter of survival for the MSE

[15] In the UK this situation is extreme: A materials bachelor graduate is unlikely to earn more than £12,000 to £14,000 first salary and a materials PhD graduate is unlikely to obtain more than £17,000 to £ 20,000 first income. An accountant or a finance graduate can start from £17,000 with a bachelors degree, and from £20,000 to £ 25,000 plus car or bonus with an MBA (in 1994 values). More balanced conditions exist in some European countries (e.g. Germany) and the Far East and mainly in Japan where the engineer enjoys high status.

departments[16]. The government could encourage and organise such activities and initiatives and provide (at least) autonomy or a legal framework for universities to be able to proceed with such collaborative programs.

4. MSE education curricula: A well-designed and MSE academic syllabus should encompass all four MSE elements (giving equal emphasis to science and engineering principles) and simultaneously establish connections with many other science and engineering fields. Further, materials academic research activities should be balanced between basic materials research (mainly properties and S&C) and applied research (mainly S&P and performance) activities. International experience demonstrates that countries with a balanced educational focus on both basic and applied research and both engineering and science strengths (e.g. Germany) have been enormously successful in converting innovative concepts into technological and commercial advantage.

5. Thematic organisation and specialisation of academic curricula: The thematic organisation of MSE academic curricula is a joint responsibility of academia, industry and government. Industry and government, through technology foresight results, ought to provide feedback of what the present and future weaknesses and needs are, and provide incentives to academia to respond to the emerging needs (Pardoe 1990). According to Stokes (1990), specialisation should be primarily delivered at postgraduate level. The government, in co-operation with the university community, can provide a framework of solid undergraduate syllabus and then co-ordinate the distribution of the specialisation of the postgraduate courses according to the specific strengths of each academic institution and ideally according to the needs and demands of industry and the needs of the national economy through extensive use of specialised scholarships and financial incentives[17].

6. Supporting skills and teaching facilities: The NRC study identified severe shortages of good S&P text books and text books which sufficiently address the integration of the MSE field with manufacturing and product or services design principles. Moreover, analysis, modelling and simulation skills are essential in materials teaching. According to NRC (1989) and Smallman (1990), despite their importance, modelling and simulation skills are usually acquired after graduation at postgraduate level and / or during training or through working experience. In addition, Chelsom, Dennis, and Kaounides (1994) pointed out that project management skills are also vital (see next page).

[16] See for example the alliance between Cambridge and Hitachi and Toshiba.
[17] The method is extensively employed by South Korea, Taiwan and Portugal.

7. Continuing education: The idea of continuing education has strategic importance in knowledge based economies but in many OECD member countries it has largely been ignored (OECD 1996). In a rapidly changing and dynamic field such as the materials field staying abreast of new developments is a necessity if skills are not to become obsolete in only a few years. Being mainly an industrial responsibility (which can initiate the creation of in-house or university continuing education courses), it is a crucial problem for people working in SMEs. Here the role of the professional societies is enhanced. Professional societies, in co-operation with universities, can effectively identify and track trends and developments in the MSE field and organise seminars or short courses for their members. Alternatively they act as government and university consultants for educational curricula reform or as co-organisers of university short courses and as information gatherers and distributors.

MSE, Tertiary and Management Education

It should be stressed that the knowledge required to understand, develop and utilise materials technologies has to be a part of specialised knowledge supported by a wider educational and technological culture[18]. Shortages of adequately trained personnel may seriously impede the expansion of firms, affect their competitiveness, compromise their technological capabilities and encourage investment abroad, directly affecting the national economy.

In addition, Chelsom (1994 and 1996), Chelsom, Dennis and Kaounides (1994) Scherer and Huh (1992) and Kaounides (1995 and 1996) have identified a number of management education requirements necessary for the successful management of the complex interaction of the MSE field with corporate and national technology and business strategies. At corporate level, they argue that the integration of materials capabilities with SE practices, the management of 'supply systems' and complex technological alliances and the design and implementation of complex materials R&D portfolios and technology strategies require a dynamic and 'holistic' management approach which can be comprehended only through sufficient education schemes.

At national level (collaborative projects) Chelsom, Dennis and Kaounides (1994) pointed out that "... project success (of large, multi-partner, complex projects) depends largely on how projects are managed by the collaborators, and has little to do with the way in which government funding programmes are structured." Hence, both technological and finance/economics education should be connected and

[18] As Prof. Bowen said (1986) after been named US scientist of the year, "We need to dramatically increase the technical literacy of the American public (...). The average American citizen must be made aware of the fact that AM are critical to the US economy... .It is the quality and diffusion of tertiary education which has the most profound effect on economic performance."

supplemented with the appropriate management principles (e.g. emphasis on co-operation and mutli-disciplinarity, synthesis of principles, systems management etc.).

Despite the realisation of these facts, education policies vary greatly among countries. The extremes are represented on the one hand, by Western countries with vast decentralised *and laissez-faire* higher education systems and, on the other, by the Far East countries (especially Korea and Taiwan), which regard education as the major national asset and development axis, and where science/engineering education planning and funding is tied directly to the national technology and industrial strategies.

5.3.2: Standards and Data bases

The importance of standardisation and databases

Before the emergence of the new global market conditions, public authorities tended to perceive standards mainly as mechanisms for protecting national markets or as barriers to international trade. International competitive pressures enabled industry and relevant government authorities to accept unanimously the utility of standardisation and the need to strengthen it, since the advantages it provides are many. Standards, apart from technical efficiency and technological reasons, establish:

- A frame of reference for assessing testing, production, and manufacturing methods,
- A frame for assessing and diffusing information about the product or material's properties and performance,
- The elimination of uncertainties concerning products, materials and their uses,
- Provision of equity between buyers and sellers in different countries and promotion of deals and international trade.

The standards issue has been underlined many times in the MSE field. Information needs are considerable since AM:

- Are not backed up by the same pool of experience as conventional materials whose strengths and disadvantages have been tested for decades, and
- Require radically new approaches with regard to the definition of properties, performance measurements, tests procedures and manufacturing technologies.

Simply put, the diffusion, acceptance and application of AM technologies largely depends on the availability of appropriate methods of materials specification, evaluation and codes of practice. Standards (and compatible data bases containing them) are literally the communication language of all technical efforts regarding materials. Unanimity and compatibility is essential (especially at international level) or during complex efforts where many components have to be integrated into a system or product. Following these lines, the US Bureau of Mines[19] and Boeing Aerospace singled out a minimum set of data and information requirements to avoid hindering the development and commercialisation of AM applications (see **Tables 5.1 and 5.2**).

However, in most segments of AM markets and technologies very few international standards (and even limited national standards) exist (Jackson 1995).

Advanced Materials Information Requirements	Advanced Materials Additional Requirements
Industrial Capacity and Costs World/country production capacity Projects shortfall or over capacity Committed and anticipated projects Price trends and projections	Universal specifications Category reduction Data Comparison Substitution
Health and Safety incidents Dissemination of information Timely basis, confirmed problems Suspected problems	Standard tests and data sets Data utilisation

Table 5.1: Materials and manufacturing data needs. (Source: Boeing Aerospace in Kaounides 1992).

Materials and Manufacturing Data Needs	
For each material	**For each process**
Raw materials resources availability	Product or process sales
Materials production by weight	Materials consumption by weight
Material production by value	Material consumption by value
Percentage use by manufacturing process	Percentage use of materials
Ranking of major materials suppliers	Ranking of major producers
Materials data base	Process data base
Disposal and recyclability data	Disposal and recyclability data
Pertinent EOA and OSHA regulations	Pertinent EPA and OSHA regulations

Table 5.2: Advanced materials information requirements (Source: IBIS Associates, in Kaounides 1992).

The most significant reason for this is the continuous and rapid change in techniques employed, testing methods used, and, most important, products and materials. Many

[19] Luis J. Sousa & Sorrell C.A., "*Advanced Materials: Outlook and Information Requirements*", Proceedings of US Bureau of Mines conference in Arlington Virginia, 1989, Information Circular IC9274, 1990.

AM and their manufacturing process for example are still in the definition phase[20]. The conditions are even worse when it comes to pre - competitive and fundamental research. Unnecessary work duplication, incompatibility or even incomparability of results and anarchy in the testing and evaluation methods are common problems.

The recognition of these difficulties led to the formation of specific national and international initiatives which are very briefly summarised below:

National aspects: Many countries have realised the importance of test methods and standardisation and have established agencies and information services[21] which have the major aim of ensuring that available sources of materials data and design knowledge are widely published and made more readily available to industry. These agencies work in close co-operation with both the national and international systems of standardisation (BS, DIN and ASTM, ISO for example) and with professional associations. Standardisation activities are mainly directed along the following lines:

- Agreement of standardised test methods and development of standard test methods,
- Availability of all validated information required on the properties and the processing of materials,
- Agreement and production of performance specifications both for specific materials and independently of specific materials or technologies (application dominated specifications),
- Gathering of the necessary data on engineering design methods,
- The development of regulatory codes (mandatory standards) ,
- The building-up of flexible, compatible and user-friendly data bases summarising all the gathered and available information.

International aspects: Over and above national programmes for standardisation, the standardisation process has an international role if only to record international tendencies, provide communication 'codes' and break protectionism barriers. Most international organisations such as ISO and ASTM cover established technologies and materials. In the field of advanced materials though, it has been widely recognised that there is a tremendous amount of pre-standardised research work included and since it is primarily pre-competitive, a common standard approach would save effort,

[20] For example some argue that it is precisely the lack of standards in entire technological fields (such as advanced ceramics)which is the main reason for the sluggish diffusion of these materials in many applications.

[21] Such as the Institute of Materials in London .

time and money. In an attempt to fill this gap the VAMAS project[22] was launched. The aim is:

- To provide international collaboration in pre-standards research, advanced measurement and data bases which will lead to the development of harmonised standards and codes of practice,
- To promote co-operation in emerging technologies concerning AM so as to encourage the use of joint mandatory standards for the manufacture of materials,
- Ensure the exchange and circulation of the information gathered or created.

VAMAS is currently managed by a steering committee under international chairmen, and pre-standards research is organised into 20 technical working areas (TWAs) embracing all important aspects of pre-standardisation research including materials classification, reliable and reproducible testing methods, materials properties determination, reference and database formats. The current VAMAS TWAs are shown in **Table 5.3** (titles only):

Wear test methods	Surface chemical analysis
Ceramics	Multiphase polymers
Polymer Composites	Super conducting materials
Bioengineering materials	Hot salt corrosion resistance
Materials data banks	Low cycle fatigue
Metal matrix composites	Cryogenic structural materials
Measurements of residual stress	Mechanical Measurements for hard metals
High temperature fracture of brittle materials	Super conducting and cryogenic structural materials
Efficient test procedure for polymer properties	High temperature fracture of brittle materials
Technical basis for a unified classification system for advanced ceramics	Statistical techniques for advanced materials inter-laboratory studies

Table 5. 3: Titles of VAMAS Technical Working Areas (Source: FT 1995).

Other international activities related to materials databases are:

A) The ISO - STEP: a number of groups worked towards the development of international standards for the electronic exchange of product data, including information about which products were to be manufactured. The results of this activity have major implications for materials data base builders, particularly in relation to standards and data exchange formats. These developments *are crucial* for

[22] The Versailles Advanced Materials and Standards (VAMAS) project was launched at the G7 conference of the seven major countries in Versailles in 1982.

user- producer collaboration, simultaneous engineering practices, and competitiveness of many firms and the their suppliers chain in the world market.

B) ASTM - Committee E49 on computerisation of materials property data: The American Society for Testing and Materials Committee E49 has a number of subcommittees looking into standardisation issues, including technology, data reporting, and data base quality and descriptions.

C) The European Commission activity on factual materials databases: A demonstration programme on materials data banks was launched in 1984. In addition to connecting 11 data banks in different countries this initiative intends to:

- Improve awareness of these data banks,
- Provide customers with the necessary training and retraining to achieve maximum accessibility and subsequently,
- Develop the market for such systems by the establishment of a code of practice for the operation of the systems and by the development of a multilingual reference vocabulary covering the materials included in the systems.

Seminars and workshops were held in all 12 (at the time) EU member states and the programme was in many ways successful in identifying issues, providing solutions and helping SMEs to gain a good chance of obtaining reliable data through a relatively cheap and friendly system.

D) The European Committee for Standardisation (ECS). This is the European analogue of ISO. As ISO, ECS is noted for being slow and somewhat out of step with the requirements of sectors with a high rate of technical change (OECD 1990).

Materials Data banks and databases

The MSE literature can be a real nightmare. Widely scattered across disciplines, literature types and countries, it combines one of the most difficult aspects of science and technology searching and information retrieval. As such, materials data banks and bases hold a key role in the computerised flow of information on materials properties, manufacturing and applications which is crucial in CAD/CAM, CNC, FMS etc. The databases available today are mainly of two types: bibliographic databases (abstracts) and numeric property databases and systems.

The first type are usually employed by information intermediaries in response to requests from end-user scientists and engineers. The second type (which emerges with rapidly increasing importance) are much more likely to be used directly by designers and engineers involved in materials selection or applications. For this type of databases, while groups of conventional materials with established economic importance are relatively well established in the literature, AM or NM pose many problems for researchers and classification specialists. According to Jackson[23] (Jackson 1994 and 1995) some of them are:

1. Standardisation of values in materials descriptions, properties, testing methods etc. and compatibility of presentation and format between different systems.
2. Legal Liability: If a designer extracts a piece of data from a data base in order to construct something and the construction fails (catastrophically) the data base provider may well be considered to be legally liable. It follows that before the values for the properties of a NM or AM are well established, the material does not appear in commercial or general purpose data systems.
3. Confidentiality: For obvious reasons, much materials information generated in the course of industrial or national security research remains confidential to the organisation who carried out the research. Duplication of efforts is a direct result.
4. Data base economics: Numerical databases are expensive to build and design because apart from objective difficulties, unlike bibliographic files, there are no established norms regarding the form and the texture of these databases.
5. Education reasons: MSE people when in training are not usually educated to use materials databases, partially because the numerical ones are a relatively new development.

The ongoing international and national collaborative efforts and initiatives stated above address most or all of these problems and it is hoped the combined efforts will lead to development of better systems which are relevant to the solution of a wide range of materials selection, component design, information distribution and technology adaptation.

As technology advances, the infrastructure must evolve as well says Prabhakar (1995), director of the US National Institute of Standards and Technology, according to whom it is time to think of infrastructure such as standards and measurement technologies as *enabling tools and underpinning technologies* that will be needed for the development of **all** high technology areas in the next century.

Given the new management tools in world class manufacturing and the power of computer networks (standardised data blue-prints can be passed on to designers, engineers, assemblers or manufacturers), standardised formats for new technologies, methods and materials will allow for more efficient Simultaneous Engineering and agile manufacturing practices, making it technologically and economically feasible to produce even more customer - tailored products and services. These developments

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[23] Bill Jackson is the manager, Materials Information, Joint service of The Institute of Materials and ASM International. He provided a direct interview to the author on 23/5/1995.

will facilitate the move to *mass customisation and virtual corporations* in the next century.

Patenting and Standardisation Strategies and Materials Science and Engineering

MSE and Patents. Given the preceding framework, the emerging questions are when and how effective can patents be in the case of materials technologies and how can the nature of materials technologies affect patents policies. The following paragraphs provide a brief analysis of these questions.

To start the analysis, one has to address the question under what general conditions (if any) can patents be effective. This point is defined by a compromise between the technological and commercial benefits of a patent, the involved costs and the frequently "invisible" risks of passing information to competitors by making a patent[24]. Levin et al. (1987) reports that firms, in most industries, view patents as an ineffective method of appropriating the returns of R&D and often prefer secrecy.

In other words, the question can take the form of how much tangible and intangible revenue can a patent create before its utility becomes obsolete, substituted, copied or weathered.

There are cases where a single patent can provide very high returns over a long period of time and a considerable head-start over competitors (e.g. biotechnology or semiconductors and other information technology patents: one or two single patent provide the basis for the establishment and growth of entire companies). On the other hand, there are cases where a cluster of interrelated patents is necessary in order to provide technological and business competitive advantages.

The differentiation point strongly depends on the nature of the patented "knowledge" and on what precisely the patent protects. Patents in materials are usually referred to chemical synthesis or composition, structure and composition, Synthesis and Processing or, more effectively, on integrated combinations of the four elements of the materials tetrahedron. Materials patents rarely concern performance and properties because they are the outcome of S&C and S&P and because similar or better performance and properties can be potentially achieved (in structural materials) by many different grain arrangements or chemical compositions. Therefore, for materials, we have the following distinctive cases:

- In functional materials (including many incremental functional materials) a single S&C patent (especially when combined with S&P patents) can be very effective and generate or preserve considerable technological and commercial head-starts over competitors because the possibility to have unique structures as a result of unique

[24] A patent can act as an alarm bell or guiding light for established and "invisible" competitors.

S&P methodologies is very high (the superconductors and semiconductors industry is based on such uniqueness).

- Similarly, in the case of advanced structural materials such as CCC for aerospace applications which are protected by clusters of interrelated S&C and S&P patents. In both cases, a constant chain of complementary, interrelated, patents protects high-technology intensity materials simultaneously with the processes to produce them or to manufacture the final product per se (e.g. semiconductors and integrated circuits). It is the case where patents maximise their efficiency.

However, in the *case of incremental improvements of structural materials*, isolated patents are rarely effective. First of all, these materials and their S&P technologies are usually the output of low-to-medium technology intensity technologies supported by well established and standardised base technologies. To patent only the S&C of an incremental structural material which can be produced by conventional S&P technologies does not provide significant advantages because it is very likely that a similar S&C will provide similar or better performance results. As such, incremental improvements in structural materials are usually kept secret until a significant and complementary S&C - S&P change (head-start) is achieved and/or when this significant change is fully incorporated into a new or radically improved final product[25].

The strategic and economic importance of standards

The strategic importance of standards in technical, technological and industrial development terms has been discussed in the preceding paragraphs. Here a clarification is necessary. There are two types of standards: standards which describe the characteristics of a finished product which are rather static and limited to the specific product, and standards which describe the performance of integrated technological systems, (materials, processes, components, methodologies etc.) which are the most valuable and dynamic. The following paragraphs focus on the last category.

The "enforcement" of international technology standards creates multiple economic and technological revenues for those who "enforce" them and multiple problems to their international competitors. To achieve that, uninterrupted chains of complementary patents are crucial for the establishment and protection of new products and processes. In the materials case, the cumulative effect of groups of constant chains of complementary, interrelated, patents simultaneously protecting

[25] A very good example is the SLIMDEK steel (developed by British Steel) claimed to be the most significant technological innovation in steel construction for over 40 years. The case of SLIMDEK is briefly reviewed in chapter 3.

materials, processes and final products over a long period of time, leads to the establishment of technologies and becomes a critical weapon in the enforcement of international standards.

The company, industrial conglomerate or the country which achieves to impose their standards in any technological field, imposes a vast *system* of complementary and interrelated patents and practically enforces their technological choices (in which they have a significant head-start) on competitors. Competitors (at both industrial and national level) are forced to modify their activities to the imposed standards, by copying or following the standards. That creates huge revenues in technology transfers and patents agreements for the winners and huge expenses and losses (such as technology transfer royalties, costs of technological adjustment, market losses, lagging behind technological developments etc.) for competitors. These losses can be very painful and detrimental for many competitors[26] leading up to technological "enslavement". Moreover, in the case of winners, standards have a cumulating positive effect on their innovation capabilities. Conversely, the enforcement of standards on competitors has a negative, detrimental effect on their innovation capabilities.

Therefore, it is crucial for industries and countries to be able to adopt to new standards as soon as they become available and if possible to pursue the enforcement of their own standards when the opportunity emerges[27]. But the establishment of standards is much more expensive, time consuming and "macro-economic" than the granting of isolated patents. Hence, especially in the case of small countries with limited industrial capabilities, the channeling of government funds to the support of standards development for technological advancement or for the harmonisation of the domestic industry to international technological developments would be regarded as a high level technology policy priority.

[26] Without a unified approach, products and technological systems designers the world over could be reluctant to embrace the benefits of new technologies. In such cases standards wars are inevitable. A recent example was the standards war over video-recorder format, won by Matsushita. The new standards war is over the new technology advanced memory chips (clearly materials technologies) between Matsushita's technologies and the technologies of Toshiba, Rohm, Hitachi and Fujitsu which are also supported by SGS-Thomson and Samsung (The Economist, August 22nd 1998).

[27] These opportunities emerge in cases where standards do not yet exist: that is emerging technologies where the specific country (or its industry) has established advantages or new technologies which are the output of technology fusion efforts.

5.3.3: Research Settings and Mechanisms for Co-operative Research

These settings usually take the form of research organisations and institutions, research networks and information gathering and distribution centres including university facilities. According to the US National Research Council (1989) they can be classified into small research groups and large research/technology centres according to their administrative structures and the capital invested in equipment and instrumentation and into three categories according to the orientation or the nature of the research they are conducting:

1. University related activities mainly dedicated to fundamental understanding, or applied but pre-competitive research,
2. Technological institutions and research centres: they are mainly involved in product and services development and support and they can operate under public or private administration,
3. Large research sites under public or national (government) control dedicated to specific missions of national interest or private interest under agreement and contract.

The lines of differentiation between these categories are frequently far from clear but with respect to size (small groups – large (collaborative) centres) the two research environments can readily be distinguished and each has advantages and disadvantages unique to its setting. Many of these differences are similar to the dynamic complementarities of small and large firms in innovation (see Table 4.3). Given that **all** research/technological organisations operate within the same national innovation system, the challenge for government is to *optimise the R&D division of labour* among the national research and technological organisations in a way that builds upon their dynamic complementarities.

Small Groups of Research: This type of organisation combines all the advantages and disadvantages of the individual (or the SMEs). Ordered upon the guidance and directions set by an individual (or a small group of 2-5 individuals and their assistants) they offer flexibility and fast response to ingenious ideas. Much progress in MSE (particularly in the area of basic understanding and breakthroughs) originates from small groups with outstanding cases the physics Nobel prizes in 1985 and 1987. Such groups are common throughout the field, mainly in universities.

These groups however, due to their small size, are not effective when large scale, systematic research is required. Frequently, the research carried out reflects the strict interests of the individual and that can lead to paths which are of no particular public or economic interest. Further, stiff competition for research support[28] has forced small research groups to focus on short-term projects rather than risk having little progress to report at the funds renewal stage which will most likely lead to reduced levels or loss of support. Unconventional, high risk research often suffers in this atmosphere. Finally, interdisciplinary research suffers in small groups. To maximise the benefits, small research groups should be encouraged to co-operate with other groups and have access to large scale facilities and funds availability on an easier time scale.

Large collaborative research/technology centres. The collaborative centres concept can be most beneficial if it provides mechanisms for several parts of the technical infrastructure to come together, so that the centre's activities amount to more than the sum of its parts. If industrial inputs are taken into consideration, the R&D results will have a natural outlet in industrial applications. The training of students and research scientists can often be combined in such an endeavour.

According to the US NRC the collaborative research centres can be categorised into three main types (Type I - III) according to the degree of dedication to MSE purposes and to the nature of research they employ (oriented basic research or applied research).

Type I collaborative centres were traditionally connected (in the US) with the activities of the so called National Laboratories whose main purpose was to serve national security interests. They were, and in most cases still are, under the control of governmental departments such as the defence, energy, agriculture and other departments. To a large extent these centres were built around major national facilities (e.g. power stations or military installations) and they have offered on several occasions their massive facilities to the MSE service in order to promote fundamental research and understanding and to develop materials for both military and civilian applications. These national laboratories are largely multipurpose, and there is an increasing tendency to work with industry in applied research. The principal characteristic though, is that these centres usually utilise large and expensive facilities that only the government can afford. They assist in expensive projects but they are not dedicated to the MSE field.

Type II research centres, namely materials research laboratories, reflect the response to the recognition of the importance of the MSE field. These *field dedicated* research centres can cover a specific group or more than one group of materials and they have strong links with the academic community, but they mainly depend on government support for capital and investment. Their aim is to promote understanding regarding basic and applied research on materials' four elements by executing government

[28] Funding is provided over a one to three year period.

programmes and in some cases industrial contracts (public agencies are the main supervisor and contractor). Defence and national security contracts are not excluded.

Type III includes centres which in some countries have been recently established (US) and for some others are a long established tradition (Japan, Germany). Their mission reflects a new approach to meet serious *technological* challenges and aim to enhance industrial competitiveness. Frequently, Type III takes the form of technological institutions including engineering research as one of the basic elements, and in many cases (Japan, Germany) there is a strong focus on production and S&P problems. Type III research centres bring together the capabilities and resources of the government, academia and, notably, industry. Researchers work on problems that are of technological importance to industry, as contrasted with the work done at the dedicated materials laboratories which specialise in more general application knowledge. Type III centres are formed around specific technological areas (industrial clusters which are or are not entirely materials dedicated) and their titles indicate the specificity of the objective of each centre (e.g. the Advanced Ceramics Centre, Composite Manufacturing S&E, Biotechnology Process Engineering, Robotics Systems and many others). There can be as many Type III centres as emerging technologies or technologies of significant economic and technological importance.

Mechanisms for co-operation (Research co-operation schemes)

Co-operative research entails the joining of technical and financial resources to pursue areas of collective interest and achieve specific goals. Co-operative mechanisms include research networks or research consortia involving many research partners of all types (e.g. industry, academia, public agencies, research and /or technological institutions). These efforts take many forms such as joint ventures, research consortia, industrial consortia (mainly in Japan) and many others. The organisation type and the aims of each co-operation scheme vary considerably from country to country. However, the concept of co-operative R&D is more common in Europe and Japan than the US. In many European countries for example, there is an extensive network of industrial associations with independent laboratory facilities, usually operating under a government subsidy along with some formal basis of industrial funding. Another notable international example are R&D programs conducted under the EU auspices representing one of the most extensive collaborative efforts in existence. Materials technologies are represented with the Brite/Euram programs[29] (see chapter 10) requiring direct participation and funding contribution by private firms and a commercial application analysis for each project proposal (Brite/ Euram 1994/98).

[29] Basic Research in Industrial Technologies for Europe (BRITE) and European Research in Advanced Materials (EURAM).

An increasing number of national materials policies (e.g. Japan, Germany, South Korea, USA) rely heavily on government orchestrated R&D collaborative programmes. According to Bach et.al. (1995a,b), CEC (1991/92), and Krull, et.al. (1991), implementation methodologies and participation conditions are as important as the targets of the R&D collaborative schemes. Given the findings of chapter 4 for the role of materials users and materials producers, it could be deduced that in the materials case collaborative R&D programmes would become more efficient when participation conditions and implementation methodologies simultaneously involve both materials users and producers in a complementary manner.

5.4: Shaping a national materials strategy

The first step in shaping a materials strategy is to identify some general initial parameters to be taken into account:

i) National characteristics: The first issue must be the identification of the national characteristics, specificities and particular materials needs of the domestic economy and industry. Such country-specific factors include:

a) *The economy size:* In the case of a country with large domestic market the range of materials priorities and portfolio of technologies can be still relatively wide, spreading in many classes (if not all) of materials and many types of processing and production techniques. In the case of countries with small domestic markets and a limited amount of industrial assets, the approach tends to be narrower and more specialised. In that case the direction of efforts has to be based on selected groups of materials crucial for the most competitive national industries after taking into consideration national priorities and international trends in technology and trade.

b) Shortage or abundance of natural resources: This is a very basic and fundamental consideration. A fundamental objective of many highly sophisticated materials strategies is to create materials and technologies leading to energy and natural resources independence and self-sufficiency restricting outsourcing costs and external dependence (e.g. Japan). Alternatively, when natural resources are abundant, materials programmes mainly concentrate on the exploitation of the potential of these resources.

c) Market targeting: Identification of areas (industrial sectors) of traditional strength or areas which either have or can potentially provide international competitive advantages. Attention should be drawn mainly to emerging technologies and industries. If some of the declining industries are crucial for the national economy, materials strategies for their revitalisation are identified.

ii) Technological capabilities. Materials priorities need to be compatible with other important technological efforts and priorities. That can be achieved if materials priorities are tailored (or simultaneously designed) according to the capabilities of the existing technological base (e.g. traditional strengths, industrial and research capabilities, national R&D infrastructure, human resources and others).

iii) National innovation characteristics. Technology and materials strategies are largely affected by the characteristics, historical origins, strengths, weaknesses and arrangements of the established national system of innovation (Nelson 1993). Among the most influential factors are the existence of a national industrial and technology strategy and a number of supporting infrastructure elements such as quality and availability of workforce, commitment to kaizen management principles and a stable financial environment. A realistic materials strategy must take all of these factors into consideration.

iv) Diffusion mechanisms. Chapter 3 argued that, however important, materials related technological change and spillovers can be slow. Knock-on effects from major materials programmes are not automatic and the adaptation of new materials technologies is usually not a spontaneous response. Harnessing the benefits of new ideas and materials technologies depends to a large extent on the scale and speed of their diffusion into the economic and industrial structure which largely depends on the availability of information (hence the need for standards) and the degree of acceptance of new materials by designers and engineers and on the scale of demand (if volume production can be justified). Therefore, a materials policy must employ effective diffusion mechanisms to channel R&D results into the industrial, services and academic environment taking into account all these issues.

v) Funding capacity and cost considerations. Funding capacity and secure flow of capital certainly influence the programmes to be set up especially in the materials field. In this respect a major issue is to adjust the capital allocation mechanisms which are frequently unfavourable to investment in AM technologies and research (see also chapter 6). The complexity of the MSE field and the number of agencies involved add greatly to cost. Moreover, the specific national characteristics of industrial structure or research systems may make the price of the attempt to make materials programmes work prohibitive. This is typical when an appropriate supporting environment is missing, that is when the involved infrastructure is limited or non-existent. For the same reasons efficiency can also be reduced.

Points for attention. The literature review indicates that there are some visible dangers a materials strategy would do well to avoid. Such dangers are:

a) Imbalance in the funding or excessive emphasis on basic (or pre-competitive) research as opposed to competitive research[30], marginalisation of the university system with regard to research (Japan), insufficient attention to market demands or technological trajectories (European countries) and dispersal of efforts (smaller countries). However, market signals are admittedly not very clear in all AM fields. Firms are often misreading or ignoring these signals. Governments should play a more active role in increasing the levels of awareness by creating institutional mechanisms to bring materials producers and users together in areas of common interest (e.g. the Japan Research Center for Metals).

b) Endogenous problems: The number of institutions or agencies involved and the complexity of many materials projects have a slowing down effect on the process of designing and implementing a MSE strategy[31]. Procedures must be kept as simple as possible and bureaucracy should be kept to a minimum. However, it has been found that the most centralised governments are not necessarily those who have set up materials strategies promptly and effectively. In general, countries seem to identify the degree of co-ordination necessary through more empirical means and in a manner consistent with their economic thinking and planning. The aim is to avoid wasting resources without suppressing creativity or contradicting the efforts made.

c) *SME or new - comers* are frequently at a disadvantage in the allocation of funds for major materials R&D programmes. Large firms have the advantage in the allocation of funds (due to size, established credibility, experience to ask for support, internal resources and connections). Consequently, there is always the risk that firms or institutions will misuse their technological and scientific experience and credibility to submit either second choice projects or limited interest projects, which they would not otherwise be able to finance sufficiently.

d) Allocation of funds: If the funds allocated to AM are to be used effectively, the national R&D programmes must be managed strictly and be finely tuned with the real needs of the economy. According to the findings and recommendations of chapter 4, Kaizen management principles and the appropriate management training of policy designers (see section 5.3.1) are essential requirements for successful management of such complex programmes.

[30] Many countries (e.g. India) have focused too many of their efforts on pre-competitive scientific research gaining scientific excellence but poor or too slow commercial success.

[31] A major element of the US materials strategy is concentrating around the effort to cut down bureaucracy, co-ordinate the parties involved and simplify the communication / organisation procedure.

Finally, a country's defence policy may have an effect on its materials strategy. This is mainly the case of large economies (e.g. USA) where defence and national security priorities play an important role in NM and AM development and they create considerable spin-offs towards civilian applications. This is possibly not an important factor for smaller countries apart from the notable exception of Israel.

5.4.1: Classification of national materials strategies

After identifying the main parameters involved, government programmes proceed to define the range and nature of the national materials priorities. The more abundant the natural resources, the larger the size of the economy, and the higher the level of technological sophistication of the economy/industrial structure the more multi-level and multi-target the materials policy will be. Differences in national approaches depend upon the ways in which the above mentioned parameters are interpreted.

Despite the variety in interpretation, all types of national materials strategies include the strategic concepts of making-up lost ground when a lag has been observed in a sector or a particular group of technologies, and generating technological innovation when it is expected to provide substantial commercial spin-offs and competitive advantage. These concepts are addressed by:

A: Application-oriented R&D strategies: that is pushing forward and directing R&D in areas and priorities concerning tangible, existing or near future problems (short to medium term response) or responding to problems originated through competitive pressures (e.g. making up lost ground) and arising performance requirements in technologies and industries.

B: Mission-oriented R&D strategies: these mostly involve basic or pre-competitive research activities and they usually concern emerging technologies that show promise of application across several fields (generating new technologies and markets). Elements of fundamental undirected basic research are also included.

This approach is adopted by Germany and Japan and lately by the US and France and as the two actions of this approach are clearly complementary in terms of both time horizons and strategic aims, there is a strong tendency to become a general trend throughout the world.

An OECD report on AM policies (1990) identified four patterns of national materials strategies based upon the materials entity involved. The patterns and their major exponents are:

- An overall approach – the USA and possibly Russia and China,
- A co-ordinated selective approach – the Japanese (and possibly the Brazilian) pattern,
- Prioritisation of a limited number of MSE fields – the pattern of major EU countries,
- Limited technological choices and market niches – the pattern of most small industrial or industrialising countries.

For reasons of clarity during the presentation of examples of national materials strategies, the present study adopts the OECD categorisation

5.5: Examples of national materials strategies

The following sections are an overview of the most important elements and characteristics of the national materials strategies in the US, Japan, Germany, the UK and a group of small industrialised or partly industrialised countries (some of the ex-EFTA group and South Korea). The aim is to provide illustrative examples of the role of the government in materials technologies, which can be used as reference paradigms by any national materials strategy.

5.5.1: The overall approach as illustrated by the USA case

The US national materials policy provides an example of a very large, multi-target policy aiming to retain or regain world-wide technological and commercial leadership in as many fields as possible. The US technological and materials decisions have a significant impact on the rest of the world because they act as general trend makers for many other countries.

In February 1993 the Clinton administration openly acknowledged that technology acts as the engine of economic growth and is the source of international competitiveness and national prosperity. Within this framework the Clinton administration wishes to promote technology as a catalyst for long- run competitive growth by:

1. Directly supporting the development, commercialisation and deployment of new technologies and especially best practice manufacturing technologies,
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.

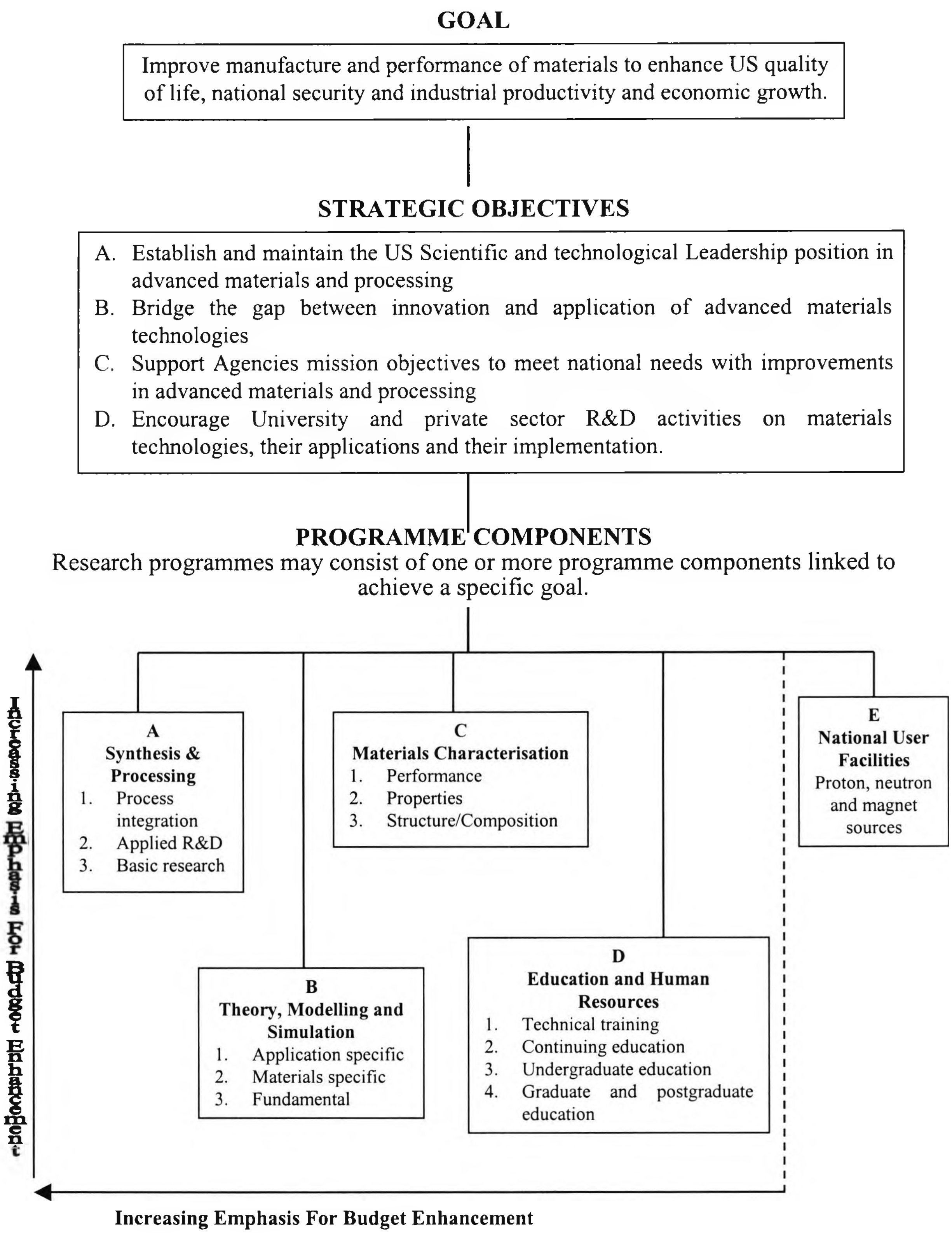

Figure 5.1: US Advanced Materials and Processing Programme (AMPP).
Source: FCCSET 1993.

In line with these measures, the basic guidelines of the current US *materials policy* are provided by the Federal Programme in Materials Science and Technology entitled Advanced Materials and Processing Programme[32] (**AMPP**). The AMPP is a goal-driven programme based on a planning framework of both strategic and technical priorities (see **Figure 5.1** for a schematic outline of the AMPP programme and **Table 5.4** for the targeted materials priorities and a budget breakdown of the FY 1992-1994 with respect to materials class[33]).

Agency	**Year**	**Funding**	**Agency**	**Year**	**Funding**
Bio-molecular Materials Biomaterials	FY94 FY93 FY92	172.2 153.5 139.8	Optical and Photonic Materials	FY94 FY93 FY92	153.3 162.9 138.3
Ceramics	FY94 FY93 FY92	199.7 166.1 152.1	Polymer	FY94 FY93 FY92	122.6 108.7 100.7
Composites	FY94 FY93 FY92	199.7 225.3 184.7	Superconducting Materials	FY94 FY93 FY92	133.0 145.2 142.7
Electronic Materials	FY94 FY93 FY92	220.6 244.2 230.5	Other/Non Materials Specific	FY94 FY93 FY92	194.5 203.0 170.8
Magnetic Materials	FY94 FY93 FY92	26.2 24.1 32.0	Subtotal	FY94 FY93 FY92	1736.4 1822.5 1683.5
Metals	FY94 FY93 FY92	254.7 389.5 391.9	National User Facilities	FY94 FY93 FY92	320.0 271.6 250.0
Total Programme	**FY92**		**FY93**	**FY94**	
	1933.5		2094.1	2056.4	

Table 5.4: AMPP R&D Budget by Material Class* ($ in millions) (Source: FCCSET 1994).
*Excludes classified research and development, and most development activities funded under DOD's specific systems R&D programmes

The aim is to improve manufacturing (S&P) capabilities and the performance of materials in order to enhance the nation's quality of life, security and economic growth. To achieve this goal, programmes are designed to optimise Federal materials R&D by AMPP activities divided into five technical components, each identified as critical to sustain progress in materials science and technology. The technical components rank in priority from level (A) - top priority, to level (E) - lower priority. In brief the components are:

[32] Detailed presentation of AMPP is provided by the *'Advanced Materials and Processing: The fiscal Year 1993 and 1994 program'* by the FCCSET Committee on Industry and Technology.
[33] All budget figures include only focused AMPP programmes, not the complementary Federal programmes. AMPP makes sure there is co-operation and there are no overlaps and duplication of efforts.

A. S &P - encompassing the creation of New Materials and processes, applied R&D to transfer laboratory achievements to pilot plants, and process integration with design and manufacturing requirements.

B. Theory, modelling and simulation - exploiting US leadership in computational techniques, to expand quantitative understanding of complex materials and processing technologies.

C. Materials characterisation - focusing on the interrelationships among structure, composition, properties and performance (basic knowledge critical to the expedient and confident use of new materials)

D. Education and human resources - assuring a continued supply of qualified educators and practitioners in the multidisciplinary field of MSE

E. Major national user facilities - providing the national laboratory and experimental strengths and infrastructure into the services of MSE (for example using synchrotron equipment for materials characterisation).

Four other initiatives by the Federal Co-ordinating Council for Science, Engineering and Technology (FCCSET) assist AMPP's technical activities towards the programmes' overall goals and objectives. These are:

- High Performance Computing and Communications assisting in theory, computing and modelling with provision of algorithms and software,
- Biotechnology Research addressing common concerns in the processing of materials by biological systems and the production of biomaterials,
- Science, Engineering, Mathematics and Technology Education initiative assisting in education and human resources support,
- The AMPP will be linked with the developing initiative in Advanced Manufacturing Technology, which focuses on integration for the advancement of innovation and application of manufacturing technology.

The AMPP is monitored and reassessed annually by the Committee on Materials (COMAT) based on R&D plans submitted by ten participating agencies (such as the DOC, DOE, DOD, NASA, NSF and others).

According to the above, the AMPP programme signifies:

1. The need to enhance materials R&D activities in all four elements of the materials tetrahedron giving particular emphasis on S&P and performance
2. The need to bridge the gap between materials basic understanding and their technological and commercial applications

3. The need to identify both materials and horizontal priorities determined by the strategic importance of the end application
4. The need for better planing and co-ordination of the Federal materials activities
5. The need for the efficient support of the national materials activities by the development of generic skills (e.g. simulation and modelling) and provision of the appropriate infrastructure
6. The need to encourage R&D collaboration between public-private sector and promote multidisciplinary approaches in the MSE field.

Given that all these priorities have been highlighted by many major reports on MSE, (e.g. NRC (1989), DOC (1990), NSF (1991)), the AMPP is a tangible example of how strategic technology policy recommendations can become policy directives within a brief period of time.

Moreover, the AMPP programme signifies a number of general technology policy perception changes. These changes are characterised by:

- A shift of emphasis from basic or defence related research to a more balanced R&D portfolio including federal support for commercial application oriented research. Given the strong scientific US knowledge base, the US government takes an active role to re-direct R&D efforts to manufacturing and civilian oriented applications[34] having as parallel concern the more effective translation of technological advantages into commercial products and military systems.
- A shift from decentralised to centrally co-ordinated administration modes by applying higher degrees of central control and co-ordination. The modus operandi of federal agencies is under modification in order to achieve better internal co-operation and encourage even greater effectiveness in areas with mutual benefit to industry.
- A shift from individualism to multidisciplinary approaches and government-industry co-operation.
- A new emphasis on infrastructure issues and a recognition of the invisible but critical value of infra-technologies.

[34] For example the change of the rate between civilian and dual use R&D to pure military R&D funding (from 41/59 in 1993 to 50/50 in 1998) and the review of all federal labs managed by DOD, DOE, and NASA which can make a contribution to civilian technology by devoting 10-20 % at least of their budgets to commercial R&D partnerships with industry.

5.5.2: The co-ordinated selective approach as illustrated by the case of Japan

The Japanese national materials policy provides an example of a co-ordinated selective materials policy aiming to retain or regain world-wide technological and commercial leadership in selected technological and commercial fields and/or gain strategic resources independence. Japan was the first country to officially identify materials technologies as emerging technologies and as crucial determinants of competitive advantage (since the early 1980s) and among the first countries which have developed a distinct and coherent national materials strategy as an integrated part of the national technology strategy. Hence, the Japanese national materials policies have developed significant strengths, which act as reference or inspiration points for the national materials strategies of many other countries (especially in the Far East). The most important of them are:

Determination of priorities. The priorities of the Japanese national materials policy are defined by a combination of *vision and need.* With respect to *vision*, the Japanese government has considered it important to provide many sorts of relevant information, obtain *opinions*[35] and achieve *consensus* from different sectors of Japanese and, in some cases, global society. The selected materials priorities explicitly aim to create (or support) a strong lead in *civilian-oriented* emerging technologies with the greatest commercial potential (e.g. materials for electromagnetic and electronic applications), and in a small but strategic number of pre-selected military applications[36]. In addition, the relatively limited absorption capacity of the Japanese domestic market has promoted strong export-oriented tendencies.

With respect to *need*, being short of practically everything, Japan has been probably the first to identify the economic and strategic importance of materials shortages. The objective of many of the Japanese national materials priorities is the development of materials substitutions (mainly new materials) based on local ores and minerals, which will substitute or minimise the need for imported materials, save resources, capital, energy and, most of all, strategic dependence on other nations[37].

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[35] Elaborate Technology foresight studies designed and implemented by the Science and Technology Agency *(STA)* and the Ministry of Trade and Industry (*MITI*) provide valuable feedback.

[36] For example, Japan has achieved world leadership (Toray Industries) in the production and manufacturing of Carbon-Carbon Composites (CCC) which dominate many aerospace applications, while rapidly expanding in performance demanding civilian applications (e.g. construction).

[37] For example, this is one of the aims of the national R&D project on High - Temperature materials. The target of the programme is to establish the basic technologies for the development of inter-metallic, fine ceramic and composite compounds with superior strength, oxidation resistance and toughness able to operate at high temperature environments (up to 2000 ^{o}C). This is also demonstrated by the emphasis on fine ceramics for structural applications and advanced composites for civilian applications.

Long-term systematic commitment. The systematic pursuit of long-term visions and goals constitutes an important means of formulating science and technology policies in Japan. The case of the R&D programme on basic technologies for future industries (JISEDAI programme) indicates that the same perspectives apply in the MSE field.

The JISEDAI project (launched in 1981 by the Ministry of Trade and Industry) was designed to promote R&D on fundamental and emerging technologies, which can underpin the emergence of a new generation of industries in aerospace, information technologies, energy, construction and biotechnologies. For each project a "basic R&D plan" is established with pre-set development targets, in order to monitor progress and evaluate results over a ten years period. In 1992, there were eleven ongoing projects. As **Table 5.5** demonstrates, nine out of the eleven were pure materials projects. *None* of the projects spans less than seven years[38]!

Project Name	R&D Period (FY)
Super conducting materials and device	1988-1997
High-performance ceramics	1981-1992
High-performance material for severe environment	1989-1996
Photo-reactive materials	1985-1992
Non-linear photonics materials	1989-1998
Silicon-based polymers	1991-2000
Molecular assemblies for a functional protein system	1989-1997
Production and utilisation technology of complex carbohydrates	1991-2000
Bio-electronic devices	1986-1995
Quantum functional Devices	1991-2000
New Models for software architecture	1990 – 1997

Table 5.5: Long term R&D projects in Japan. (Source: JETRO in Kaounides 1992).

Administration and co-ordination strengths. The Japanese national technology and materials policies are designed, implemented, monitored and reassessed by three dominant actors: the Science and Technology Agency *(STA)* directly linked with the Prime Minister's office, the Ministry of Trade and Industry (*MITI*) and the Ministry of Education, Science and Culture *(MESC)*. Other agencies are also important in their respective fields[39]. However, the three agencies mentioned above control 84% of the government's budget for science and technology (in 1994 values) (Sigurdson, 1995).

[38] It should be noted that the Japanese R&D system has been reformed in recent years with the introduction of the Industrial technology Frontiers Programme which continuous the long run vision and emphasis on basic materials research.

[39] There are also two top advisory councils (Council for Science and Technology and the Science Council of Japan) aiming to provide the government with necessary science and technology policy recommendations and planning.

MESC provides public funds to universities and national research centres for scientific research. STA stimulates basic research and supports new technologies within the industry. MITI formulates industrial technology plans, determines and provides subsidies, identifies areas and technologies of strategic interest (e.g. the relevant requirements for new materials developments across a range of industries and industrial applications) and acts as a catalyst for R&D collaborations between industry and research organisations. The selection, implementation and evaluation of the national R&D projects is undertaken through a trilateral framework involving very close co-operation between MITI, national research institutes, universities and private industries. The national R&D project method employs a parallel system whereby R&D activities are pursued at a number of participating research institutions simultaneously.

This centralised approach has a number of advantages:

- It achieves a high level of integration of the national materials strategies with the national and industrial technology strategies,
- Political leadership is constantly aware of the technological developments and their economic and social potential and consequences,
- It achieves high-levels of monitoring and evaluation of projects,
- It achieves a co-ordinated division of R&D labour between the participants,
- It promotes the formation of links and R&D networks between the Japanese public and private sector.

Collaboration networks and industrial links. One of the corner stones of the Japanese technology and materials policy is the creation and support of industrial links and collaboration networks. For example, the Japanese Research Centre for Metals (*JRCM*) acts as a catalyst between industry, university and government. JRCM has established a form of meetings called "*salons*" which facilitate exchange of information between *participating metals producers and users* in order to integrate market ideas and users ideas in metallic materials R&D.

Supporting facilities for MSE strategies. The Japanese MSE policies are strongly supported by:

- Profound instrumentation capabilities (Nature vol.355, 16/1/92). The Japanese may lack the Western creativity in basic research but they possess supreme instrumentation design and manufacturing capabilities for use in the MSE field. Such tools give an unparalleled advantage in conducting excellent quality, cutting edge research in materials.

- Manufacturing and processing strengths. Strong commitment to these principles has laid strong emphasis on materials S&P which has been the determinant factor in superior technological innovation and world class performance in several industries.
- Commitment to continuous improvement and Kaizen principles.
- Ability to diversify and transform. It is not a surprise that major Japanese materials producers identify common areas between classes of materials and diversify (gradually) their resources and activities to emerging materials while restricting the range of activities for declining materials classes[40].
- Financial and industrial support. In Japan, the private sector dominates the funding of R&D to an extent at which there is hardly a parallel in other industrialised countries. Many, if not most, of the large companies have set up central research laboratories which increasingly pursue both applied and long-term exploratory research. Several of the very large companies maintain separate basic research laboratories where researchers have almost the same freedom as in academic institutions. However, the government still plays an important role in shaping the research agenda and shoulders the financial burden not only for big science but also for emerging scientific and technological themes (Sigurdson,1995).

Japan is a notable example for its commitment to importance of materials. As many Japanese executives put it "*He, who controls materials will control technology.*"

The Japanese MSE establishment is a highly structured enterprise and has been instrumental in many past technological successes. Even though it is composed of conventional organisational elements and strategy instruments quite similar to those used throughout the world, what is *atypical* is its *system approach*. The Japanese approach systematically pursues long-term targets and demonstrates the long-run effect and commitment which has to exist in all materials efforts and strategies. Additionally, Japan is a specialist in forming highly complex industrial networks, public -private collaboration schemes, technology acquisition and information exchange and diffusion mechanisms so that the technical and commercial opportunities can be identified and grasped as soon as they appear. Contrary to common belief, the government and the various agencies (e.g. MITI) act *only* as a catalyst and industry takes the lead role as performer of R&D.

Moreover, Japan demonstrates how a national materials strategy is shaped by taking full advantage of national capabilities and limitations. First of all, Japan has long ago recognised the accumulated value of manufacturing and processing skills and of

[40] See for example the case of Nippon Steel and Toray Industries in Chapter 3.

infrastructure and infra technologies, and through decades of continuous improvement has acquired excellence in these areas. Japan has solved problems related to manufacturing, inventory, delivery times and other supporting facilities. Hence, technology policy makers are in a position to know immediately what impact a materials strategy will have and what special issues have to be addressed first in order to support this strategy.

Within this frame, Japan has clearly a wide-ranging but selective materials strategy targeting both entire materials groups (e.g. fine ceramics, new metals) and special materials for specific final applications. The majority of emphasis is given to incremental, or known materials, which exhibit the greatest commercial promise, usually within each firm's domain and traditional strengths. New materials development also takes place, functioning as preparation for the future and as a source of learning and acquisition of basic research R&D skills while benefiting from the end results. The emphasis on specific areas (e.g. advanced ceramics) reflects the forecaster's confidence in the researchers and engineers abilities to solve the technical problems involved and the realisation of the many possible applications and future externalities of these materials.

A major element in the Japanese materials and technology policies is the acknowledgement of significant weakness in the area of basic research and scientific excellence. Recognising this weakness Japan is moving to re-orient R&D into basic research areas while gradually integrating domestic skills and strengths into the restructuring processes. Scores of modern R&D laboratories have been constructed by many corporations while internationalisation and location of R&D activities abroad and employment of the best local human resources are parts of the effort to bridge the gap. By the year 2000 Japan will employ 350,000 scientists and engineers in high technology innovative projects - nearly twice as many as the US (Fortune 18/5/92).

5.5.3: Examples of prioritisation of a limited number of Materials Science and Engineering fields

This approach is adopted by large European industrial nations such as Germany, UK, and France. The materials priorities and the implementation methods are as diverse as the needs and special characteristics of each country[41]. In all cases, the most common

[41] The German materials strategies philosophy is much closer to the Japanese approach for example, whereas the UK approach was until recently quite similar to the "old" completely decentralised US approach. France and Italy have a strong traditional governmental control over their materials

attitude is to give emphasis to areas where the specific country already possesses pockets of excellence while keeping a closely monitored number of priority research/technology fields in a parallel and complementary stream of activities. Usually the State has the role of identifying critical areas and pushing forward with the expense and risks of fundamental research, while industry has the responsibility to carry out commercially oriented research according to their individual interests.

Case study: the German materials strategies

The German materials policy remains faithful to traditional industrial strengths (e.g. engineering, chemicals and metallurgy) of the German NSI, while a selection of new areas such as high performance ceramics is included in the national materials priorities.

Strengthening Germany's position in innovative products and processes is the main objective of the Federal Ministry for Education, Science, Research and Technology (*BMBF*). The BMBF plays the role of a catalyst in advancing R&D in fields where innovative results are expected. Projects eligible for BMBF funding must involve both industrial and non-industrial laboratories as partners. Research priorities in the MSE field are primarily set by counselling from the manufacturing industries which use these materials. BMBF distinguish R&D strategies between application oriented and mission oriented (pre-competitive or basic research) strategies.

If a project is to receive government funding, its research proposal must describe the resulting commercial benefits or the potential technological applications. It is also a requirement that the project should entail a relatively high level of scientific and technological risk so that if it is successful the resulting innovation is significant. State funding is available for both fundamental and applied research, in both industrial and federal laboratories. This funding continues until the market potential has been demonstrated. Then, the related industries take over.

The new materials programme is a typical applications oriented R&D strategy example. Especially promising fields, where new materials are expected to play a trend-setting role are given high priority. Equal ranking is also given to the development of NM, improvement of existing materials, and materials manufacturing and processing. The part of the NM programme devoted to new physical technologies is divided into three areas: new technologies, surface engineering, and high temperature superconductors. Efforts are also concentrated in a number of end

strategies and some countries - Spain for one - have structured their materials policy and choice in accordance with EU materials choices and selections.

applications such as developing better or new materials for turbines and engines to raise efficiency and cut fuel consumption and pollution, transportation, lightweight materials for transport applications, and smart materials for actuators, sensors, control systems and electronics. As in Japan, ceramics and metals and new chemical compounds and processing methods attract most of the efforts.

Mission oriented pre-competitive or basic research funding is given to emerging technologies that show promise of applications across several fields. The first task is the identification of suitable technologies through the use of inexpensive pilot projects. To do this, the BMBF uses as collecting points for knowledge a small number of institutions and experts in industry and academia. *Interfaces* between established technologies are good places to look for new technologies and, apart from basic research, engineering and market potential parameters are examined simultaneously. The information results are condensed into discussion papers and feedback is provide by academic and university experts. The resulting consensus is then taken by the BMBF which initiates R&D projects. Special attention is given to diffusing the results of these initiatives. Target areas examples include catalysis, sonochemistry, and non-linear dynamics[42] .

Case study: the UK materials strategies

The UK national materials policy provides a very interesting example of a well-balanced and "rounded", selective type of national materials policy which has been in the process of a notable transformation of its perspectives during the last seven years.

According to Humphreys (1992) prior to 1992, it was widely believed in the UK that R&D in materials should have a low priority because new or advanced materials developed elsewhere could always be purchased or manufactured under licence by UK industry. Moreover, the government did not identify priority areas letting the market choose alone. Interdisciplinary project approaches and proposals were rare and materials development and implementation programmes were strongly connected to short term market needs. Research was mainly focused on materials properties and the S&P role was neglected or overlooked. These perspectives, Humphreys continued, had some force in the 1970s and 1980s but were becoming increasingly unsuitable by 1992. Japanese industries for example would neither sell nor licence certain materials seen to be of key strategic importance[43]. In addition it became apparent that for many

[42] The information regarding the German materials policy was provided by Dr Bechte (1992), general director of new technologies in the German BMBF.

[43] This became painfully apparent in the silicon case: The UK cannot purchase first grade silicon in the international market place: only second grade is made available to the UK.

advanced materials it was not a question of buying processed materials and then making components. Processing the materials and fabricating the final component are often fully integrated.

The Technology Foresight Programme (1995). Major changes to the UK approach were introduced with the findings of the White Paper on Science And Technology - Realising Our Potential Report (May 1993) and the Reports of the Technology Foresight Programme - Progress Through Partnership (1995) conducted under the auspices of the UK Office of Science and Technology. The Technology Foresight Materials Committee and the Steering Group identified a number of important issues:

- First of all, they underlined that the UK cannot rely on buying in materials and materials expertise; it has to have its own materials skills and competencies if its industries are to survive.
- They identified that the materials and chemicals fields (they define them as separate entities) are science and technology driven sectors and they are constrained primarily by technical feasibility. These sectors are characterised by competitive advantage often accruing from new technology products and by having many diverse products[44]. Moreover, the Committee pointed out that in the long-term, competitive advantage is more likely to come from the continuous improvement of existing materials and processes through new scientific, engineering and technological advances and from a multitude of incremental advantages rather than radical advance in isolated fields. Hence, the Committee identified the need for the U.K. to target generic materials technologies and/or materials with a wide spectrum of applications from which many industries can simultaneously take advantage.
- They suggested that new or improved *structural* materials rarely create new products. They can however significantly improve existing products[45]. On the other hand, new or improved *functional* materials can create new products very rapidly (e.g. laptop computers, pocket-sized mobile phones).
- They underlined the importance of S&P and they recommended that in the case of advanced (but existing) materials (e.g. superconductors) and emerging technologies, more of the available research funding would do well to be devoted to processing of advanced materials into useful components and less into the search for new advanced materials.

[44] According to the committee, the materials industry is not a detached field; income is generated from sales to other sectors. Hence, the economic significance of materials is many times greater than the revenue they generate directly by the sales at the beginning of the supply chain. This was also underlined by the OECD (1990) report on '*Advanced Materials: Policies and Technological Challenges*'.

[45] For example, the jet engine preceded nickel or titanium alloys. The new and improved high temperature structural materials have made the jet engine much more efficient.

- They emphasised the need for the U.K. to support the development of generic MSE skills (e.g. support for S&P, education policies, simulation and modelling, materials testing and evaluation).
- They highlighted that multidisciplinary approaches and technological and R&D networks between industry, academia and governmental laboratories are important to provide the advance techniques and knowledge to solve complex technical problems and minimise costs and risks.
- The materials panel included industrial users and producers/suppliers of materials indicating that the design of a national materials strategy must take into account both types of industries and the interactions between them.

Within this framework the foresight initiative identified five categories of required R&D in materials science and technology:

I. *Optimisation of Currently Employed Technology*

All currently –employed materials and processes are capable of further developments to further meet the needs of particular company and the product they make. Most materials today are not developed for the application they are employed. Given that materials can be tailored to meet specific requirements, vast opportunities for improvement exist.

II. *New and Improved Tools and Techniques*

Currently-employed materials and process can be improved by employing new and improved tools and techniques. For materials, examples include surface treatments, better testing and evaluation methods etc. For processes, examples include applications of simulation and modelling in processing technologies, sensors, advanced joining methods etc.

III. Breakthrough Technologies for Applications Limited By Currently Available Materials Properties.

This is products and technologies which are limited in performance by materials limitations. A breakthrough in materials technologies has the potential to enable significantly better end products or systems of products and technologies. Materials and processes which are needed to reduce environmental damage come into this category

IV. *Emerging Science And Technology – Science Driven Longer Term R&D*

This category include speculative work, which, if successful, could, when combined with other products and technologies create new markets. Topic in this category are likely to take a very long-time to come to market, if ever. (Note the similarity with the German and Japanese mission-oriented research).

V. *Curiosity – Driven / Blue Skies Research*

The Materials Panel recognised the need for the U.K. to continue to invest in this type of research.

Priority topics in each of the categories I-IV (see above) of required R&D were identified. The priority topics are mapped into categories with **Figure 5.2**.

As we can see from Figure 5.2, particular emphasis is provided in materials groups from which many industrial sectors can benefit simultaneously. For example, note the complementary interlocking between sensors and computer applications in S&P modelling and the case of high – temperature materials.

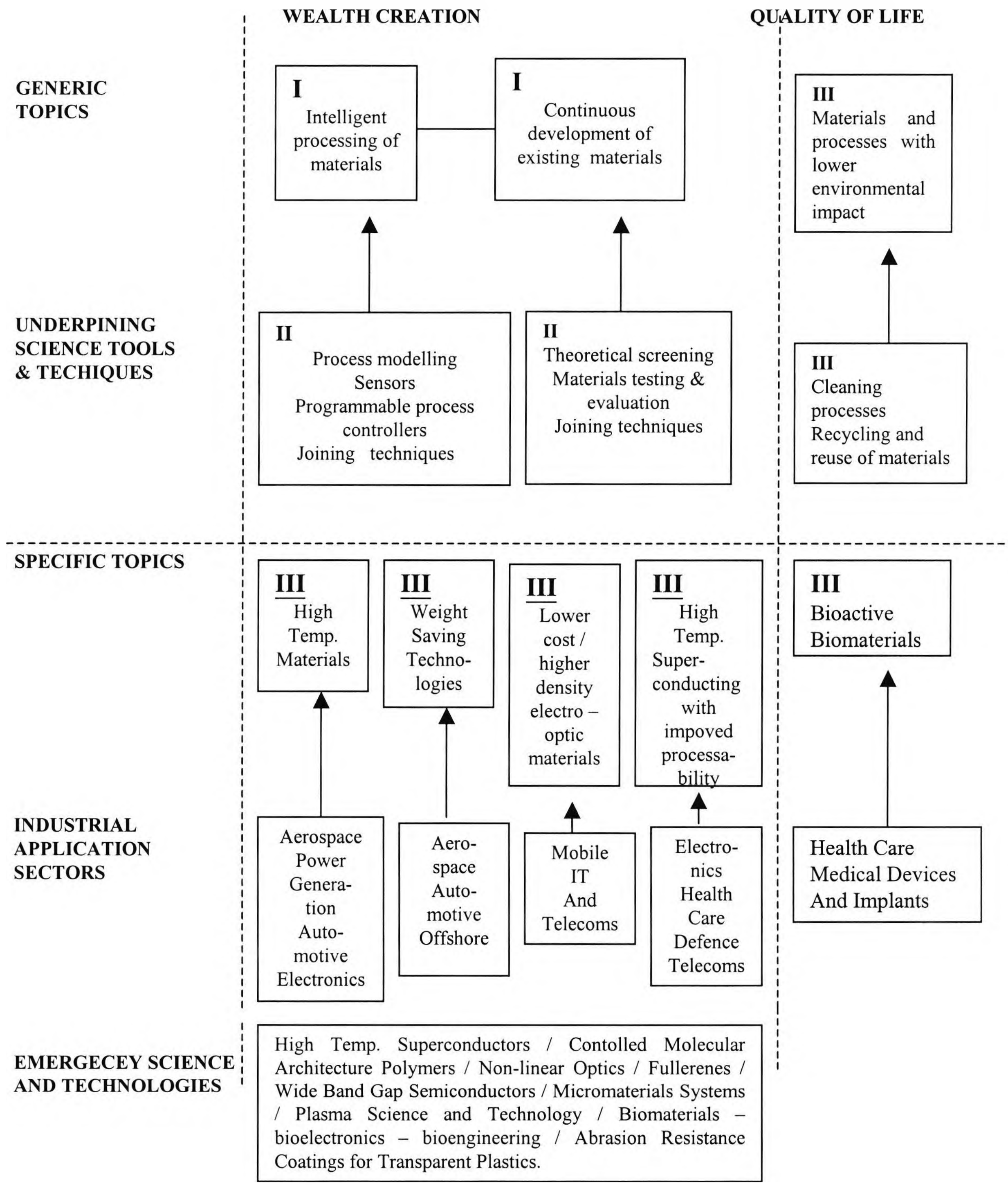

Figure 5.2: The U.K. National materials priorities / priority topics. Source Technology Foresight, DTI 1995.

In addition, the Committee identified a set of generic infrastructure priorities (horizontal priorities) aiming to create a national "critical mass" or support existing generic capabilities applicable to all elements of the MSE field. These include:

1. MSE and *Education*: that is the necessity to improve and maintain a strong national science and technology base and to improve the training and education of the MSE scientist and engineers by restructuring MSE courses in higher education at both undergraduate and postgraduate level.
2. Research in the Science base: that is *maintain support* for truly excellent *basic research,* provide new incentives for multidisciplinary research, and incentives for universities and research councils to work with the industry [46].
3. Finance: Development and encouragement of long term finance for R&D and innovation including the continuous review of fiscal measurement, special incentives for SMEs, and enterprise architecture.
4. Policy and regulation: that includes (among others) intellectual property rights protection, procurement by the government as a stimulus to leading edge technologies and continuously updating the scientific basis for standards and measurement methods.
5. Links: that is the promotion and support of linkage of Universities and other research institutions to the applied research and industrial needs and establish simple mechanisms for government funded partnership programmes.
6. Integrate supply chains to define wealth creation and quality of life targets for research.
7. Review research assessment exercise criteria to promote inter - departmental collaboration.
8. Science watch professorships to monitor and assess global R&D.

The UK materials and technology strategy as expressed through the Technology Foresight reports marks a significant departure from traditional perceptions and moves in line with strategies in the Far East, but moulded to meet the conditions of the British national system of innovation.

[46] Frequent interaction between science and business about market and technology trends and opportunities is no longer seen as an optional extra; it is an essential component of long term competitiveness.

5.5.4: EU materials policies: The BRITE/EURAM Programmes

What is really significant in Europe is the overall European materials and technology strategies under the Brite/Euram Framework. EU materials strategies are the largest example of national and international collaboration including active participation by all the major players in the materials field. The Brite/Euram programmes mainly concentrate on the injection of funds into pre-commercial and pre-competitive research covering all four elements of the materials tetrahedron and on training and personnel mobility issues and they reflect the attempts by EU to form a European materials strategy.

EU has still many problems to solve before a solid European strategy emerges. However, the Brite/Euram programmes reflect to a large extent the prevailing way of thinking and choices in Europe. In return, the EU materials strategy choices affect the choices made by many European states as they can act as pilots or reference points and potential resources for the formation of their own national strategies.

The special character of the Brite/Euram needs special attention; therefore, a brief analysis of the priority objectives and aims of the Brite/Euram programmes as elements of the official collective EU materials strategy is reserved for chapter 10. Further analysis of the Brite/Euram programmes with respect to the Greek case is also presented in Chapter 10.

5.5.5: Approaches based on specific choices and market / application niches

This approach is adopted by small countries or economies which have limited capabilities and resources. In small countries, deciding which materials and industrial policy must be followed is critical and becomes more critical if a gradual industrial shift in the national industrial character is attempted. Large countries like the US, Japan, and Germany can afford to push forward in wide portfolios and a variety of selections. If one of the selections fails their economies and structure can absorb the shock and the other selections will probably repay for the lost resources. In small countries a selection failure can be very damaging indeed. Consequently, most small countries adopt a selective strategy which reflects their actual and potential materials capabilities and other national strengths. Typical examples were the materials priorities of the ex-*EFTA* countries (Sweden, Switzerland, Norway, Iceland, Finland, Austria)[47]. Small EU countries like Denmark and Ireland also fall into this category. The materials R&D efforts in ex-EFTA countries and small EU countries, are very much determined by:

- The availability of indigenous resources, skills and technological capabilities (e.g. steel improvement and processing, powder metallurgy in Sweden / concentration on structural materials (mostly metals) for offshore engineering, energy applications and hydrothermal power plants in Norway).
- Strong commitment to safety and reduction of negative environmental impact and exploitation of natural resources (e.g. Norway - waterfalls, Iceland - geothermal energy).
- Type of economy and particular strengths in the domestic industrial structure (e.g. steel technologies in Sweden, polymers in Denmark, off-shore technologies and materials in Norway, materials for geothermal applications in Iceland).
- Experience in sectors with stable or rising world wide demand (e.g. mechanical engineering in Switzerland, chemicals in Austria and Switzerland, instrumentation development in Denmark, textiles in Ireland).

In addition, the materials policies of these countries may opt for a policy of widening the industrial and technological base and transforming the character of domestic industry (i.e. changing from low technology intensity products to high technology products - e.g. from textiles to advanced fibers and composites; from bricks to advanced engineering ceramics). This approach is more common in small industrialising countries such as South Korea (in the 1960s and 1970s) Taiwan and Portugal.

Case study: the South Korean materials strategies

The South Korean example has been chosen because it illustrates a number of issues related to national materials (and technology) strategies:

** All small European countries share a common characteristic: when materials strategies began to be formulated some technology, science and engineering skills were readily available. South Korea began formulating a materials strategy simultaneously with a national technology strategy from scratch, having no previous scientific or engineering excellence of any kind to support these efforts. The technology and **materials strategy** was designed to assist and even become a major source of restructuring of the South Korean economy.

[47] Since 1996, Sweden, Finland and Austria joined the EU.

** The South Korean industrial development and economic transformation has gone through materials related industries (the ten biggest national industrial groups – most of them multinationals- are materials producers or intensive materials users (e.g. Samsung, Hyunday, Daewoo, Kia, Lucky Goldstar etc.). The South Korea economy up to the early 1960s was a labour intensive, agricultural economy with many problems inherited from the Korean war. In the early 1960s South Korean policy makers set the target for South Korea to become a fully industrialised country with a technology intensive economy by the year 2000.

** South Korea is a notable example where government intervention has overcome the weaknesses of small domestic markets. Industrial development proceeded rapidly because of a strong government intervention that places science and technology in a favoured position and rewards the corporations and organisations that are most successful in promoting international trade[48]. Target technological and materials areas were identified: in the 1960s it was steel and consumer commodities, large scale construction industries for transport applications and the ship building industry. In the late 1970s they targeted electronics and semiconductors as areas with explosive commercial potential and applications.

** A fundamental aspect of the South Korean materials, technological and industrial efforts was (and still is) the systematic creation of generic supporting skills and the systematic channelling of considerable capital from the commodity or low technology intensity profitable industries to the high-technology targeted industries. Other typical characteristics of the South Korean national technology and materials policies are the heavy use of the "infant" industries and national champions idea, and the mobilisation of capital through a financial, industrial and banking system, until recently under national control. Another feature is that South Korea provides the most striking example of the power of "oriented" education as a means of technology transfer and domestic skills acquisition. For decades South Korea "directed" its people (through grants, scholarships, and fellowships for undergraduate and mainly postgraduate students) to targeted areas[49], providing financial support to students studying abroad and ensuring employment after graduation.

** With respect to current materials strategies, materials research is divided into two major categories: incremental materials improvement and import reduction (as in the case of Japan) and NM and AM development for supporting the

[48] South Korea for example, in order to help domestic industries in their export efforts introduced two kinds of tax incentives: i) The more profitable the companies were, the less tax they paid for the share of profits coming from exports. ii) If, say, a company had to import raw materials for a product which was then exported, the import or consumption taxes for the imported materials were removed (Shin & Kim 1994).

[49] Of 3000 PhD students in South Korea 10% work on MSE issues.

commercialisation of emerging technologies and creating generic skills. The former category is supported primarily by industry whereas research in the latter category is financed almost exclusively by the government in a public-private co-operative system (KAIST 1993). The materials projects include all classes of materials but they target specific areas of end applications which comprise the ten national technology projects identified as urgent priorities to be supported and promoted by the South Korean government in the early 1990s. In 1992 South Korea embarked on the HAN or G7 project along the lines of the Japanese national R&D projects.

While South Korea is an example where government intervention has overcome the weaknesses of small domestic markets, this was achieved due to the political and socio-economical conditions which cannot exist in a small Western European nation. But the South Korean and similar Far East governmental policies can provide some examples for former East European countries where the government has still a strong grip on the national economy. Nevertheless, ideas and methods coming from the South Korean paradigm (e.g. "oriented education") can be applied to both Eastern and Western small European countries with high possibilities of success.

5.6: National materials strategies and emerging trends

The US national materials strategy is summarised by the AMPP programme. AMPP is a notable case because it comprises a combination of horizontal priorities tailored to meet the needs of the MSE field[50] with a wide portfolio of materials-specific priorities which target an equally wide range of applications. In addition, the US national materials strategies signify a notable sift from pre-competitive and basic research dominated R&D portfolios to more balanced portfolios including both pre-competitive and applied research projects. That comes after the official acknowledgement by the US government that national basic and pre-competitive research strengths alone are not sufficient to ensure long-term industrial competitiveness. The successful integration of US research with manufacturing skills is expected to pose serious threats to EU and Japanese industries in the future.

On the other hand, Japan provides an very good example of a country which has a long record of linking its materials strategies to industrial and natural resources needs and future visions (or "dreams"). Japan is at present unrivalled in manufacturing and is currently building up her domestic and international R&D skills, is rapidly

[50] The emphasis of AMPP on the element of S&P and on simulation and modelling and education issues, points out that the US Government acknowledged that public efforts had failed in some elements of the materials tetrahedron compromising the competitiveness of the American industry.

developing basic and pre-competitive research strengths and moving beyond imitator to creator of new technologies. In addition the Japanese national materials (and technology) policies have provided vivid illustrations of the development of links and technology-based industrial networks, as well as examples of design and implementation of large scale, complex and long-term R&D projects.

The EU is still struggling to obtain a synchronised, solid and co-ordinated policy, somewhere in the middle of basic research excellence (UK, France) and engineering and technological excellence (Germany). Efforts are being made to integrate and improve simultaneously in both directions through the Brite/Euram programmes. Notable are the cases:

- Of Germany which addresses its national materials priorities through a balanced approach between mission oriented (pre-competitive research) R&D projects and target-oriented (applied research) R&D projects and,
- The U.K. which provides a very good example of a well-rounded selective approach which targets generic materials technologies from which many industries can take advantage, simultaneously with the development of generic MSE skills (e.g. support for S&P, education policies, simulation and modelling, materials testing and evaluation) addressing all four elements of the materials tetrahedron. In addition, the UK national materials policies provide emphasis to both pre-competitive and applied materials R&D and to both incremental and new materials and processes.

Finally, small countries are struggling to find a role among this high technology based global competition between the dominant industrial regions of the world. The achievement of technical, scientific, manufacturing and technological excellence in areas of traditional strength and/or selected areas of high potential is seen as the most reasonable approach as it can provide global advantages in a selected area, keeps the country's capabilities in pace with the global developments, protects the strengths of domestic industries, creates generic skills and ensures that the country is at least an *intelligent technology and materials user* and does not slip into the technological outback of the global community. Notable are the cases of South Korea (simultaneous development of industrial – technology and materials strategies) and the education policies practised by South Korea, Taiwan and, partially, Japan.

5.7: Conclusions

The literature review and the selected case studies indicate the following:

- There is sufficient economic rationale for the government to take an active role in supporting and promoting the development, adaptation and diffusion of enabling and emerging technologies such as materials technologies. Especially in the case of small economies with limited resources and capabilities the role of the government is much more critical than in larger nations because of market failure and the weaknesses of the national system of innovation. The extent of government intervention varies considerably but a centralised and co-ordinated approach is a common general characteristic and trend shared by all the reviewed nations.
- The role of the government can be summarised under the three basic principles of identifying areas of importance and indicating directions, providing a favourable environment for the incubation, support, development and diffusion of these technologies and, design and implement R&D and other activities (such as large scale national R&D projects) in these directions.
- The major directions and priorities of a national materials policy (i.e. which materials for what applications and how many priorities) are basically restricted and defined by the availability or lack of natural resources, the characteristics of the national economy and industry, the characteristics and strengths of the national R&D infrastructure and the national system of innovation, and (probably above all), *the kind of vision* the policy makers have for the nation and its national industrial and economic development.
- Small countries with limited resources and capabilities usually choose a carefully selected portfolio of limited selections which combines:

- The development of skills and materials competencies in pre-selected wide-application (enabling) materials technologies (e.g. ceramic coating technologies, ceramics or metals for high temperature applications) form which many industrial sectors can simultaneously benefit,
- Materials priorities which build upon national strengths,
- Materials and materials technologies targeting market niches and applications.

- According to the reviewed case studies, it is mainly the scale and the number of the national materials priorities that differentiates the national materials strategies of large countries (wide portfolio of materials priorities) from the national materials strategies of small counties (limited portfolio of priorities). Given the 'inflexibilities' imposed by the nature of the MSE field[51] (see also chapter 2), the national materials strategies of both large and small countries share many common characteristics:

- National materials policies are an active part of the overall national technology and industrial policies.
- Any well-balanced national materials strategy simultaneously supports all MSE principles and all four elements of the materials tetrahedron as a whole. It also comprises the development of generic skills (e.g. simulation and modelling) necessary for the implementation and support of any national MSE effort.
- A major global trend indicates that many national materials strategies comprise both long-run, pre-competitive and /or basic materials research projects and long- to medium run applied materials R&D projects. Governments around the world put considerable effort to optimise the balance between pre-competitive and applied materials research, while, simultaneously, developing capabilities in both (see the US shift to applied research and Japan's shift to basic research).
- The reviewed national materials strategies provide particular emphasis on collaboration and the development of links and networks between firms and between industry and the national research R&D infrastructure (e.g. universities, research institutions).
- National materials priorities are usually implemented thought the design and execution of collaborative R&D programmes. Mission-oriented programmes address pre-competitive research portfolios, while target-oriented programmes address applied R&D portfolios. These programmes are usually centrally co-ordinated and their implementation is supervised either by public agencies or large research and/or technological institutions.

In addition, with respect to the provision of a favourable environment government has the main responsibility for:

- The design and implementation of horizontal measures aiming to the development or provision of generic capabilities applicable to all fields including the materials field. For example, the case of the US AMPP comprises a complementary combination of horizontal measures (action (B) and (D) - simulation and modelling skills, postgraduate education support) tailored to meet the needs of the MSE field with measures targeting specific groups of materials and specific applications.

[51] E.g. the need to support simultaneously all four elements of the materials tetrahedron, the need for multi-disciplinary approaches etc.

- The provision of R&D infrastructure able to address and support the implementation of the national materials priorities
- The provision of supporting education policies. Education policy measures usually comprise the support of MSE education at both undergraduate and postgraduate level. Given the experience of mainly Far East countries, it is possible that a combination of some degree of education curricula co-ordination in undergraduate level and some degree of directions provision through the employment of scholarships and continuous education schemes at postgraduate level has the advantage. Education policies must also comprise technical education schemes and management education schemes for managers overseeing the design and implementation of complex R&D projects.
- The provision of supporting patents and standardisation policies. National patents and standardisation policies must be linked with the national materials priorities, so that results can be patented and standardised as soon as they become available. In the materials case, systems of patents and standards comprising both new materials, their S&P and final applications are more effective than isolated patents.
- Moreover, government has the responsibility to act as a catalyst, and in some cases as a co-ordinator, to provide a favourable *business and financial* environment which assists industry's efforts to commercialise R&D and technological innovation. This involves the domestic financial market and many elements of the national system for financing innovation. These issues receive further attention in chapter 6.

These considerations are relevant to all economies but are likely to prove most critical in the case of smaller countries with weak technology and industrial infrastructure and capabilities. Each country needs to undertake a serious re-examination of its position in the international division of labour, the danger of erosion of existing sources of comparative advantage, and the financial, educational, scientific, engineering, and institutional requirements, for the selective acquisition of new sources of competitive advantage in both regional and global markets. The dangers of further marginalisation of countries within the world economy are real and extremely urgent.

Finally, two additional points must be underlined:

- Large or small country, the main responsibility for competitive products and services development remains with industry. It is industry's responsibility to protect themselves and remain competitive by investing in the MSE field because industry has both the means and the experience to convert scientific and technological advance into products in the market place (NRC 1989). Nevertheless, the strategic importance of the provision of a favourable environment for the development and commercialisation of materials (and other) technologies is more crucial than is immediately obvious. The weaker the national R&D infrastructure and the more indifferent the domestic financial markets (see chapter 6), the more companies have to compensate through their own internally generated or borrowed resources in their R&D budgets. Ultimately, that can jeopardise the competitive position of large companies and is a burden for the growth of SMEs or for economies based upon SMEs.

- A significant finding of the first five chapters of the thesis is that since materials and MSE technologies are the basis and/or the enabling tool for many other technologies, while requiring a high level of supporting technologies and facilities for their understanding and utilisation, an investigation and analysis of the level of sophistication and effectiveness of these technologies can also provide a very good indication of the general (overall) level of technology and R&D strategy in a firm, industrial sector or nation. Sophisticated materials technologies, capabilities and strategies indicates a well-balanced and highly sophisticated technology strategy; a bad record in materials technologies, skills and strategies indicates a strong possibility of the existence (or the potential development) of weaknesses in technology and industrial base.

CHAPTER 6: Financing Long Run R&D In High Technology: Incentives Availability and Sources of Capital

6.0: Introduction

The issue of availability of finance for the development, implementation and finally commercialisation of emerging technologies has been raised on several occasions in the previous chapters (2-5). However, if firms have their technology strategies linked to their business strategies and a strategic decision is taken to seek competitive advantage through the development and commercialisation of emerging technologies, the nature, characteristics and the special needs of these technologies (in terms of time horizons and capital necessary for their development and commercialisation), *automatically establish* the (long-term) availability of finance *as a fundamental pre-requisite.*

As identified in chapters 2-5, materials technologies and materials capabilities are a major source of long-term competitive advantage. The strategic decision however, to pursue competitive advantage and new business opportunities based upon materials competencies[1] automatically necessitates a long-term commitment and automatically establishes the need for long-term availability of financial resources.

To provide an example of the argument, if long-term finance is not available, the three-steps time-based framework for materials R&D[2] can not be applied. A corporation would be unable to invest in materials (and other technologies) pre-competitive research and unable to respond to "customers' dreams". Moreover, even if this corporation has adopted third generation R&D activities (as an integrated part of its business strategy), then these activities would be able to serve only short-term goals (such as trouble-shooting or small incremental improvements of existing technologies, processes and products). Therefore, long-term and uninterrupted availability of finance is a fundamental prerequisite for the development and commercialisation of materials and other emerging technologies (e.g. biotechnology).

Within this framework, Chapter 6 investigates some of the most important[3] mechanisms for the finance (or the support of finance) of technological innovation

[1] E.g commercialisation of new materials, materials-based diversification or technology fusion strategies etc.

[2] See section 4.2.6: Time-based framework for materials R&D (the Nissan / Ford model).

[3] The subject matter is vast and it is neither possible nor appropriate to provide an extensive treatment of all the issues involved in this chapter. The aim is rather to identify the key issues involved in relation to the concerns of this thesis.

and the development and commercialisation of successive generations of long-term technologies such as advanced materials technologies. Chapter 6 includes three inter-related parts.

The first part (sections 6.1 to 6.3) examines the role of the government in financing technological innovation or taking the initiative and formulating mechanisms in support of the finance of technological innovation and of risky, long-term R&D projects. It argues *that in the case of materials technologies*, technology or project focused measures are more effective than horizontal mechanisms such as general tax incentives.

The second part (sections 6.4 to 6.8) investigates the role and the inclination of major institutional investors (banks, venture capitalists) in the financing of technological innovation, (materials innovation in particular). The second part provides a brief analysis of the prevailing patterns, examines the question why some technologies attract more investments than others, argues *that materials technologies* and their needs *are not well understood by institutional investors* as other technologies (and hence not favoured by the current trends), and, finally, makes recommendations for improvement on issues such as the evaluation of technology and technological information.

The third part (sections 6.9 to 6.10) focuses on corporate level and examines the issue of financing long-term R&D efforts *from the management's perspective*[4]. It argues that SMEs have to rely on external sources of capital and national systems for financing innovation more than large firms. On the other hand, large firms can compensate for the weaknesses of the national system of financing innovation. It is argued that strategic controls when combined with financial controls, favour the allocation of corporate resources for both short and long-term R&D activities, and hence, they are the most appropriate to support materials innovations. However, the application of financial controls alone discourages (or even inhibits) the allocation of corporate resources to long-term projects and technological innovation. Chapter 6 ends with a small list of conclusions and recommendations/proposals.

[4] There is a raising Vs allocating funds issue here. One issue is the source of funds (internal – external) for R&D. The second issue is how firms decide to allocate resources to R&D and long-run R&D in particular. Given that the previous chapters analyse materials strategies adopted by large corporations (multinationals), chapter 6 makes the assumption that these companies are in position to rise sufficient capital for R&D by using either internal or external (see also sections further below) sources. Hence, the present analysis focuses on the issue of how firms decide to allocate this capital. Detailed analysis of the first issue would be out of the scope of the present research.

6.1: Economic rationale for public support mechanisms for the finance of innovation

Chapter 5 argued that there is a necessity for a national technology policy based upon welfare economics, the argument of "market failure" and the relative inadequacy of private incentive mechanisms to mobilise resources in order to reach a "first-best" Pareto optimum and maximise welfare (Stoneman 1987, Hay and Morris 1991, Metcalf 1994). Chapter 5 concluded that one of the basic elements of a well-balanced national technology policy is the "provision" of a *favourable environment* in which technological innovation has the opportunity to nucleate, grow and diffuse. Policies in this direction include the provision of a supporting infrastructure (see section 5.1 & 5.2) and the provision of a set (or system) of capital allocation/finance mechanisms seeking to enhance the innovation possibilities or the existing innovation capabilities of firms/industrial sectors (Nelson 1993, King & Levine 1993, OECD 1995c).

Indeed, a broad battery of evidence (e.g. King and Levine 1993, Nelson and Winter 1982, Nelson 1988 and 1993, Dosi 1988, Dosi, Pavitt and Soete 1990, Heertje 1988, Hay and Morris 1991) suggests that, within national systems of innovation, appropriate financial settings are important for technological innovation, productivity growth and economic development. For example, financial systems which evaluate prospective entrepreneurs, mobilise finance to the most promising productivity-enhancing activities, diversify the risks associated with these innovative activities, and reveal the expected profits from engaging in innovation rather than the production of existing goods using existing methods, improve the probability of successful innovation and thereby accelerate economic growth (King & Levine 1993).

Similarly, since the prime argument for technological advance (which requires sufficient finance) is considered to be improvements in economic welfare (Stoneman 1984 and 1987), then financial sector distortions, information asymmetries, entry barriers or inefficient financial systems reduce the rate of economic growth by reducing the rate of (technological) innovation. Given that technological change involves the parameter of time and the related issues of risk and uncertainty, and since in "perfect markets" conditions most actors are risk averse[5,6], this will lead to sub

[5]Much of R&D literature centres around the appropriability problem - can the spender on R&D sufficiently justify his spending and protect his discov
eries to obtain a reward that reflects the social valuation of his discovery, and thus will the incentives to R&D be sufficient to encourage the correct level of R&D? (also see chapter 18: '*Public policy and the development of firms*' in Hay and Morris (1991), Industrial Economic and Organisation).

optimal level of investment in risky, long-term projects. Moreover, an attempt to extend the possibilities of risk shifting could raise problems of moral hazard[7] and / or information asymmetries[8] which have a negative influence on market performance.

Given the strict conditions necessary to reach Pareto-efficiency, a direct implication is that the economy, and the financial/capital markets in particular, will no longer of their own accord approach first-best optimum conditions and the economy will deviate from welfare optimality. The major defect is simply that the market is (or will be) imperfect for a wide range of 'borrowers', particularly SMEs and new firms, that have no previous experience of financial credibility (Hay and Morris 1991). Hence, the strong possibility that (financial/capital) markets will tend to reach a "second- best " or even "third-best" Pareto optimum, decreasing overall welfare and national prosperity, provides the rationale for government intervention and the formation of policies for supporting (or reducing the cost of) the finance of innovation and its diffusion in the economy in order to increase welfare (Stoneman 1987).

Finally, there are arguments that the globalisation and liberalisation of financial markets has smoothed down financial obstacles for the finance of (technological) innovation by creating capital mobility and dissolving information asymmetries. A recent OECD study (1995) on "National Systems for Financing Innovation" has thoroughly investigated this issue and concluded that finding funds for technological innovation is still one of the most serious problems to be overcome, since the evaluation and management of risks raise acute problems which are in some cases intensified (especially for SMEs and small countries exposed to the disadvantages of globalisation), by the liberalisation of international capital markets.

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disproportionately high percentage of their innovative efforts on short-term improvement innovations neglecting long-term more radical innovations".

[7] Arrow (1962) was the first to argue that moral hazard problems hinder external financing of highly risky activities such as technological innovation.

[8] Even when firms can costlessly transmit information to outsiders, strategic considerations (e.g. protection of core competencies) may induce firms to actively maintain information asymmetries. Additionally, Levin et al. (1987) report that firms in most industries view patents as an ineffective method of appropriating the returns of R&D and often prefer secrecy.

6.2: Issues for consideration

Before discussing some widely used mechanisms aiming to support or mobilise finance for technological innovation some basic issues are worth identifying:

I) 'Total' investment in R&D Vs investment in 'physical' R&D. The concept of the "finance of R&D" should not be confused with the expenditures dedicated to create or maintain an appropriate and tangible R&D and technology infrastructure[9]. This investment in "physical" R&D (Himmelberg & Petersen 1994), is a *sub-total* of the "total" investment for R&D and includes the expenditures aiming to create a physical infrastructure for R&D including investment in new plant, equipment, machinery, data banks, and laboratories which should be kept constantly up-dated and harmonised to the firm's R&D portfolio needs.

The term "finance of R&D" or "total" investment in R&D is more general and apart from investment for R&D infrastructure it involves the total R&D investment (or expenditures) of a firm or country including the finance of the R&D *activities per se* and the intangible or even invisible expenditures (human resources, organisation expenditures, formation of information networks etc.) related to both specific projects and the entire R&D portfolio of the firm.

Failure to distinguish between the importance of the two separate but inter-connected issues probably contributes to the relative inefficiency or ineffectiveness of many mechanisms for supporting the finance of innovation in many countries[10].

II) Technological innovation and the diffusion of technological innovation.

The first observation is that the majority of the most common world-wide incentives / mechanisms for supporting the finance of innovation are oriented to support 'original' R&D. Activities aiming to support, deepen or develop the in-house core competencies of the corporation (such as reverse engineering, knowledge acquisition etc.), which

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[9] Chapter 5 defined technology infrastructure broadly as elements of an industry's technology base that originate outside the boundaries of the individual firm and which are subsequently used by the majority of the firms in that industry (Tassey 1992). Here, physical investment is connected with the R&D and technology infrastructure of the individual firm which is used for the majority of the firm's R&D activities.

[10] For example, Greece has many incentives in favour of "physical" investments in R&D while, simultaneously, the general tax and technology investment system does not keep pace in supporting long-term R&D activities (see subsequent chapters). On the contrary, South Korea and Japan have established policies which distinguish the particular importance of both "physical" investment and of investment in R&D activities *per se* and they have developed policies in simultaneous support of both (Sigurdson (1995) OECD (1995f)).

This 'inefficiency' can have a relatively superficial effect on some technologies (e.g. software development), while it can be relatively detrimental for others. In the case of materials technologies for example, since some technological competencies can not be externally acquired (see chapters 3-4), R&D activities such as reverse engineering and knowledge transfer/acquisition are a necessity, which according to the above, remains unsupported.

Secondly, at the economic level, it is not helpful to treat innovation and its diffusion as separate categories (Metcalf 1991). But most of the majority of the employed incentives / mechanisms are oriented to support R&D *per se* and not its diffusion and commercialisation. According to Piatire (1984), Folster (1991) and Metcalf (1994), it is common to think of R&D as confined to the discovery, invention and development stages of the technological change process. But technological advance and competitiveness depends on the output of R&D (the diffusion and implementation of the results) (Stoneman (1984) Freeman (1982)) which usually remains unsupported. Moreover, the diffusion of technological innovation involves interactions among a wider range of institutions supplying the knowledge, the skills and the conditions, which underpin the efforts of individual firms (Metcalfe 1994). The diffusion of materials technologies for example, requires a synergy of many actors including systems of materials producers, intermediate and final users and final customers. Therefore, policies or strategies aiming to support the finance of technological innovation, would (ideally) be expected to cover the entire spectrum from invention to diffusion and from basic research to the mastery of specific technological capabilities and involve a wide range of inter-related structures and financial institutions.

Macroeconomic policies. It should also be stressed that general monetary, fiscal and other macro-level policies, although they may impact on the process of technological innovation and technological change, are primarily targeted elsewhere (Stoneman 1987). As such they are not considered as genuine elements of a national technology policy or a policy for supporting innovation, but since they have an impact on technological change they receive further attention in following sections.

6.3: Public support mechanisms to mobilise finance for civilian technological innovation

According to the OECD report on national systems for financing innovation (OECD 1995), in a market economy a financial system performs three main functions:

- The provision of capital (OECD 1995c).
- Supervision of the way capital is used, and,
- Creation (and re-allocation when necessary) of resources.

Within this frame, **Table 6.1** summarises the most common examples of world-wide employed public mechanisms for financing or supporting innovation. They can be classified into those which take the innovation possibilities of firms as given and via various measurements try to enhance these activities, and those which seek to generate or enhance these possibilities (Metcalfe 1994, Stoneman 1987). Some basic elements of the first category include:

- Policies which seek to reduce the cost of research to the firm such as R&D subsidies of various forms and tax incentives for R&D (e.g. tax deductions for R&D expenses or other forms of tax relief and grants towards the cost of R&D personnel).
- Policies aiming to increase the pay-offs to innovation either in terms of general public procurement of R&D intensive products or through the duration and scope of patent protection[11] (Nordhaus 1969; Lichtenberg 1988),
- Policies which aim to set a frame that helps (and even promotes financially) the formation of collaborations and information storage and diffusion,
- Export - import policies and measurements,
- Policies in support of the institutional investors[12].

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[11] Or *standards enforcement.* This argument is a critical issue, largely neglected and it receives further attention in Chapters 7 and 8 where the standards policy in Greece is discussed and analysed.

[12] The aim is to mobilise private finance for innovation by reducing the cost of capital or the involved risks for the institutional investors. Mechanisms in this direction include:

- Mechanisms to reduce the cost of investors (e.g. public bodies make an ex-post payment to the investor (equity guarantee schemes) in case of failure of investment - e.g. Germany).
- Mechanisms to increase the liquidity and the rewards of investors (e.g. securitisation of exit mechanisms),
- Mechanisms to reduce the current cost and / or scale of investment (e.g. public bodies give an *ex--ante* for the investor when investing in a specific type of business)
- Mechanisms to attract new type of investors not familiar with innovation financing (e.g. in Denmark the Danish Technological Institute acts as a broker between individuals that want to invest in growth companies and entrepreneurs with good innovation proposals).

Mechanisms in support of Innovation	Non-Technology Specific Policies	Technology/ Sector Specific Policies	Flexible in use policies[13]
Tax incentives for R&D	X		
R&D procurement contracts		X	
Project grants		X	
Project loans at low interest rates			X
Conditional loans (that are repaid only if R&D is successful)			X
Free – based loan guarantees			X
Securitisation of markets for new products / services		X	
Royalty grants / stock option grants			X
Patents policies	X		
R&D collaborations schemes (finance not included)	X		
Financial support for R&D collaborations			X
Government measures in support of the institutional investors			X
Import – Export policies	X		
Entry barriers[14]			X
Macroeconomic measurements	X		

Table 6.1: Forms of public support mechanisms to mobilise finance for innovation (Source: OECD (1994a,b) OECD (1993), Mansfield (1986), Boekholt and Fahrenkrog 1994).

Policies aiming to change the innovation possibilities of firms would include:

- Initiating and financing (at least partially) collaborative R&D programmes,
- Policies aiming to link the internal efforts of firms with public R&D carried out in the science base (universities, research and technological institutions),
- Policies which aim to motivate firms to undertake long-term R&D projects by contracts, by royalty or stock option grants[15] and/or by securing future markets for the targeted products or services,
- Free– based loan guarantees (for a fee of a small percentage (usually 2% - 5%) of the size of the loan, 100% of the project cost can be borrowed at market interest rates. In case of bankruptcy the state picks up the loan).

Two issues emerge. Firstly, an important element is whether policies for financing technological innovation are to be directed at firms irrespective of their technological areas or whether they are to focus on specific technologies. If the latter, it should be recognised that the special characteristics of each technology have a strong influence

[13] Can be both technology / sector and non - technology / sector specific.

[14] It is becoming difficult to impose entry barriers without violating international agreements. However, many countries still impose severe import restrictions to a wide spectrum of products and services (e.g. Japan, South Korea, China etc.).

[15] Royalty to the state is based on sales of the invention towards which the grant was applied. Stock option grants: in return for an R&D grant, the state receives a stock option that can be exercised if the stock value rises significantly. For large companies the stock option refers to separate venture companies set up around the respective R&D project.

areas or whether they are to focus on specific technologies. If the latter, it should be recognised that the special characteristics of each technology have a strong influence on the way the basic guidelines of a general policy are applied and implemented (Boekholt 1996).

Secondly, while some mechanisms such as public procurement of R&D intensive products, or contracts which secure future markets, can be "product", technology, or industrial sector (or even firm) specific, others like those seeking to reduce the cost of research to the firm, such as generic R&D subsidies and tax incentives for R&D, can not be technology or product/firm specific. While the latter group of policies clearly aims to support the creation or accumulation of competencies and skills of more generic kinds, and is generic in character and application, the former is specific target and strategy oriented and it usually illustrates examples of a more "active and vigorous" governmental intervention within the framework of a national technology or industrial policy.

The two streams of action are (or should be) inter-related and complementary and their simultaneous, combined, action usually achieves the best results (Rosenberg 1982).

6.3.1: Comments on the effectiveness of some innovation subsidies

Table 6.1 provides only a brief overview of the most commonplace mechanisms which are used to support technological innovation world-wide. These mechanisms differ considerably from country to country, with respect to what is subsidised, what form the subsidies take and under what conditions the subsidy can be received (OECD 1995, Nelson 1993). But a closer look at the policy discussions concerning subsidy instruments gives the impression that many subsidy instruments are often chosen for their administrative advantages rather than their efficiency in generating additional R&D, or especially, diffusing and commercialising its results[16] (Folster 1991, Piatire 1984). The following is a brief critical overview of the relative effectiveness of some of the mechanisms and policies mentioned in Table 6.1. in connection with the special needs of materials technologies as they have been identified in chapters 2-4 .

General Points. According to Folster's findings (1991) on the efficiency of innovation subsidies, general (*horizontal*) application subsidies (non-technology

[16] One must be careful in the evaluation of effectiveness of the mechanisms under question; R&D is an input not an output and just because R&D increases, it does not mean that innovation and technological advance is spontaneously generated.

to all research/technological fields means that the impact on any particular field is small. But other subsidies such as R&D contracts or market securitisation, (which can be specialised or even 'individualised') were thought to have a greater effect. In more detail:

Taxes and R&D. Tax reductions, credits and initiatives of various forms and types are used by many countries around the world. According to Bhagat & Welch (1995), tax incentives are used because a firm's tax environment will influence positively its investment decisions including R&D investments.

However, the effectiveness of tax systems in increasing R&D expenditures varies accordingly to the way they are applied and the aim they serve[17]. For example, at corporate level, Folster (1991) concluded that small firms were not affected in particular by tax reductions while, simultaneously, were thought to be in greater need for readily available capital. Bhagat and Welch (1995) also concluded that in sum, the ability to deduct R&D expenditures from current taxes seems to be most valuable for large firms paying more tax. At national level, Mansfield (1986) concluded that reductions have a positive effect on R&D expenditures of 13% - 14% or more in both Canada and Sweden. In a more recent study, Bhagat and Welch (1995) concluded that in contrast to the US tax code, the Japanese tax code manages to encourage R&D more effectively.

At technological level (e.g. support for materials technologies), two more issues have to be identified.

The first issue has to do with the application of tax credits *per se*. Taxes and many other horizontal incentives have a very general character and thus two fundamental weaknesses:

- They have not (so far) taken into account the complex relationships necessary for the commercialisation of a complex technology such as materials technologies (that is they act superficially), and,
- They are not always designed to be complementary with other subsidies such as loans, grants, collaborative schemes, thereby reducing their effectiveness.

The second issue has to do with distinction between 'total' investment in R&D and investment in 'physical' R&D. Tax incentives targeting investments in R&D equipment and infrastructure alone, (like the research experimentation credit tax in the

[17] According to Karageourgiou (1996), tax incentives are more effective when both their spirit and their implementation are of "good will" and they really have scope to support companies in their activities. If a tax incentive is or can be used as a checking instrument for the real profits of a company, or it is too demanding in its application then the results are expected to be poor.

equipment and infrastructure alone, (like the research experimentation credit tax in the US) are particularly useful for expensive technologies[18] but they should be used with caution because they indicate support for capital investment against labour investment for R&D (Ellis 1994). Supporting only the acquisition of the equipment and not the equally expensive use of the equipment (that is the finance of people and projects) will not have the desired effect. Therefore, a complementary tax system is necessary in support of both physical and general expenses for R&D.

Government contracts and procurement policies in specific technologies / industries. Stoneman (1987) and Folster (1991) reviewed existing evidence and concluded that direct government R&D spending on civilian applications does not necessarily crowd-out privately financed R&D but definitely encourages it. It is thus seen as a rather more effective instrument than tax credits.

When it comes to the support of research *per se*, the more focused the objective of the supporting mechanism the more effective its action will be. For example, direct research supporting mechanisms for R&D in Norway work best because there is a clear division between exploratory government funded generic R&D and industry financed applied R&D aiming at specific applications.

Markets securitisation (sales of products or services guaranteed by government) is regarded to be the most effective assistance to technological innovation and its diffusion (Stoneman 1987, Doutriaux 1991). In addition, markets securitisation is the main 'tool' in support of "infant industries" during their uncertain first steps and until the targeted firms/sectors learn and gain experience in volume production[19] which is very important in advanced materials. Selective purchases can also work as a means of rejuvenating existing industrial sectors by providing a sales guarantee until the initial transformation/rejuvenation investment pays off. Doutriaux (1991) for example, pointed out that in the case of Canada, and especially when it comes to high-technology start-ups or spin-offs, firms starting as government suppliers do significantly better than firms receiving other types of government support at start-up. The former firms tend to be better organised and they are more export-oriented than these other firms. And, Doutriaux concludes, government contracts for goods and services are more important to the future growth and success of the firms than contracts for R&D and other R&D support mechanisms.

[18] R&D in new materials for example involve expensive technology and they require very expensive laboratory and experimental equipment.

[19] Large government contacts concerning large scale construction programmes aiming to improve the conditions of the national public infrastructure in, say, transport or energy are good examples of indirect but efficient civilian R&D subsidies.

towards intensive materials users (and occasionaly producers), and when they are combined with additional auxiliary subsidy measures such as taxes and/or export policies.

Import / Export policies. Raising entry barriers is becoming increasingly difficult- not to say internationally illegal (violation of the GATT agreements – see Gatt 1994 and the directives of the World Trade Organisation). Import/export policies however, can still be useful in the following terms:

i) Promoting (sponsoring) and supporting exports (by international deals) or assisting in the creation of an international trade network. In many countries entire industrial sectors have been developed with an internal market orientation. These industries lack experience in penetrating foreign markets and in establishing international distribution and promotion networks. As a result these types of firms/industries face severe problems when trying to develop an export strategy. Government can provide much counselling, financial incentives, and organisational assistance in this area (e.g. solving international legal issues through political negotiations, setting international trade agreements or using national diplomacy as a means of leverage in order to ensure or create new markets).

ii) By giving economic and financial bonuses (e.g. tax incentives, low interest long term loans) to companies which significantly contribute with their exports to the country's income.

Loans, grants, guarantee schemes, stock options and royalties. According to Folstrer (1991), within the EU, the free - based loan guarantee schemes are viewed with suspicion. It was thought that unless they contained a large subsidy component they would be taken up largely by those already planning to default. The scheme has been used heavily, however, with various results by countries with strong governmental intervention in the economy (e.g. Greece, South Korea). The stock option grant and the royalty grant schemes were thought to be attractive because "they resemble what private investors do". Since firms initially receive a grant their leverage is not affected, and the self-financing component is activated in proportion to the success of the project. Therefore, these instruments were thought effectively to reduce risk while, at the same time, providing the state with a way of recouping costs.

These mechanisms, however, are more difficult to be monitored and supervised and they mainly *support industrial rather than technological* innovation. In addition, their implementation requires the involvement of a third party, usually an institutional investor in the form of a big commercial or investment bank or a governmental institute for the finance of innovation which provides the cash liquidity or acts as an intermediary in the transactions.

institute for the finance of innovation which provides the cash liquidity or acts as an intermediary in the transactions.

Macroeconomic measures (exchange rates). A critical question in the finance of R&D and technological innovation is how macroeconomic policies, like the cost of capital and exchange rate changes, such as appreciation or devaluation of national currencies, affect private investments on R&D and innovation projects. The following relations apply:

Cost of capital: the higher the inflation rates the higher the cost of capital. That has a negative impact for technological innovation and mainly affects SMEs with limited internal fund raising capabilities.

Currency exchange rates and R&D expenditures: To begin with, changes in the real exchange rate are a key driving force behind the sector resource allocation of the economy. They affect the competitive environment of individual companies as well as industrial sectors in a variety of ways. Theoretically, an appreciation intensifies import competition while making it more difficult for exporters to maintain their position in overseas markets. It works like a combination of import subsidy and export tax. Conversely, a currency devaluation has the opposite effect, and has been used many times as "a tool" for enhancing international competitiveness.

Zietz & Fayissa (1994) by investigating R&D expenditures data on 360 U.S. manufacturing firms over the years 1975 to 1987 concluded that only firms in industries with average R&D spending of at least 3% of sales revenue reacted to an exchange rate appreciation with increased R&D spending. Firms in industries with lower levels of R&D intensity did not. This finding can be interpreted to mean that only R&D intensive firms react to an increase in competitive pressure with more R&D effort. Moreover, Zimmermann (1987) using cross selection data for a large set of German companies, found that increased import competition and more integration in foreign markets appear to raise R&D activity for *exporting* firms relatively to non-exporting firms. Since we know (Hughes 1986; Maskus 1983) that industries with a large export share are also those with a high R&D level of activities, Zimmermann's findings can be interpreted to suggest that only companies with a high level of R&D activity react to more intense R&D competition with more R&D investment. Similarly, for the USA, Zietz & Fayissa (1992) found that high tech industries increase their R&D more in response to increased import competition than low- tech industries.

Therefore, exchange rate policies such as currency appreciation or devaluation have little impact on non-R&D intensive firms while the R&D intensive firms react accordingly which verifies Stoneman's point (1987) that macroeconomic

Macroeconomic policies and private investment in R&D: Macroeconomic policies such as exchange rate changes (especially devaluation of national currencies) can theoretically increase the competitiveness of currently existing products and services for only a short period of time but not the long-term competitiveness of national industries. By making existing products and services internationally cheaper, sales can temporarily peak, "buying" some time and providing some extra profits which should be directed to further R&D or on other real competitiveness improvement measures. On the other hand, a depreciation "spoils" low-technology exporters because it makes their products cheaper while at the same time gives a blow to high-technology exporters because a currency depreciation has an immediate devaluation effect on their investment in R&D and an immediate loss of returns. As such, a devaluation of currency temporarily increases the competitiveness of low-technology firms and discourages high-tech firms from undertaking further R&D. On the contrary an appreciation of currency encourages high R&D exporting firms to spend more on R&D because they have to rely on the real competitiveness of their products based on performance and utility and not just on price competitiveness.

To provide a materials paradigm, a devaluation temporarily increases the competitiveness of 'bulk', conventional materials producers while an appreciation encourages advanced materials producers and users to further invest in R&D projects.

6.3.2: Conclusions: Materials technologies and public mechanisms for the support of civilian innovation

By viewing the total action of the various mechanisms for the support of innovation, with respect to materials technologies, the following observations can be deduced:

- Public measures in support of the finance of technological innovation and R&D should address not only original R&D but also activities aiming to support, deepen and expand the knowledge base of the corporation. Given that materials competencies cannot be externally acquired, this recommendation is particularly valuable for materials technologies.
- Public measures in support of the finance of R&D and technological innovation should address not only R&D activities but also mechanisms aiming to support the development and diffusion of technological innovation.
- Horizontal incentives such as general unconditional tax incentives, patents policies and grants that are unrepayable (that means without monitoring and supervision) have low impact on R&D and technological innovation. Moreover, incentives

- Horizontal incentives such as general unconditional tax incentives, patents policies and grants that are unrepayable (that means without monitoring and supervision) have low impact on R&D and technological innovation. Moreover, incentives supporting the development of R&D infrastructure are particularly useful in the materials case but, if let alone, cannot efficiently support the development and diffusion of materials technologies. With respect to materials technologies – a typical example of enabling and rarely end-product technologies - the most influential incentives are selective incentives imitating the effect and the behaviour of external venture capitalists or other institutional investors (e.g. grants, long-term market securitisation, procurements).
- Individual elements of a public policy for the support of the finance of innovation should (ideally) form a coherent system of complementary actions. Given that the diffusion of materials technologies requires a synergy of many parties including materials producers, intermediate and final users and final customers, firms must be addressed not as individuals but as "organisms"/parts of industrial networks and clusters with which they are in constant interaction. Hence, the support of networks and formation of financial institutional mechanisms for their support emerges as a necessity (UK Technology Foresight 1995).

6. 4: Institutional investors and their role for the finance of innovation

6.4.1: The role of institutional investors in a national innovation system

According to OECD (1995), financial and production spheres are closely interlinked. Hay and Morris (1991), pointed out that private firms will have to carry considerable risks in search for competitive advantage. If, however, companies (or innovators) cannot raise internally[20] sufficient funds for the finance of their innovation portfolios, they are prepared to look for external sources of capital provided in the form of either equity or debt by capital markets and institutional investors. Given that many of the greatest barriers encountered by innovators are still connected with financial resources[21] (Piatire (1984), OECD (1995), CEC (1998)), in a free market economy, institutional investors hold a central role in the provision, circulation and allocation of resources for innovation.

[20] E.g. sufficient profits, returns from investment schemes etc.

[21] Despite the globalisation and liberalisation of financial markets which has smoothed or resolved many obstacles.

national policy for the finance of innovation[22] (Nelson et al. 1993). Their characteristics, their policies and the implementation of their strategies define the characteristics of national financial systems and their efficiency in supporting technological innovation (OECD 1995). Through the institutional investors, the (national) financial system does not only allocate and manage resources but helps to set them up through the mechanisms of creation of resources, provision of capital and supervision of the way capital is used.

6.4.2: Types of institutional investors

Innovators need both long-term capital and working capital. The former for R&D, technology acquisition or adaptation, the setting up of mass production facilities, diversification strategies etc. The latter to cover transition periods, periods of growth, product or services launch etc. In addition, companies (or innovators) can face the need to raise externally capital for the finance of their R&D and innovation activities at any stage of their development or growth history.

According to the Commission of the European Communities (1998), their needs are usually met by four basic types of institutional investors: investment and commercial banks, general or specialised venture capitalists, business angels and other public or private agencies/institutions providing services and/or finance for technological innovation[23]. Given that the equity needs of a company vary considerably over time, a 'division' of roles among the four basic types of institutional investors is necessary. **Figure 6.1** depicts the company equity financing needs over time as correlated to the most appropriate institutional investor.

Institutional investors provide capital to potential innovators and start-up companies either in the form of debt (investment and commercial banks, business angels) or equity (venture capitalists/ investment banks) according to the choices of their own individual investment portfolios (Guild and Bachher 1996, Carr, Tomkins and Bayliss 1994, Green 1991).

The first type (commercial and investment banks, portfolio investment companies) usually want optimal returns on investments from their capital. They provide capital mainly in the form of debt, its character is rather short to medium term and the innovator should be of established financial or assets credibility to secure investments.

[22] Banks under governmental control and governmental agencies for the financing of innovation.

[23] Large institutional investors like pension funds allocate resources through their share holding investment portfolios or other schemes but usually they do not directly provide capital to innovators. Their role is examined as shares and portfolio investment holders in following sections.

mainly in the form of debt, its character is rather short to medium term and the innovator should be of established financial or assets credibility to secure investments. Hence, they are more suitable for large companies and for projects requiring huge amounts of capital.

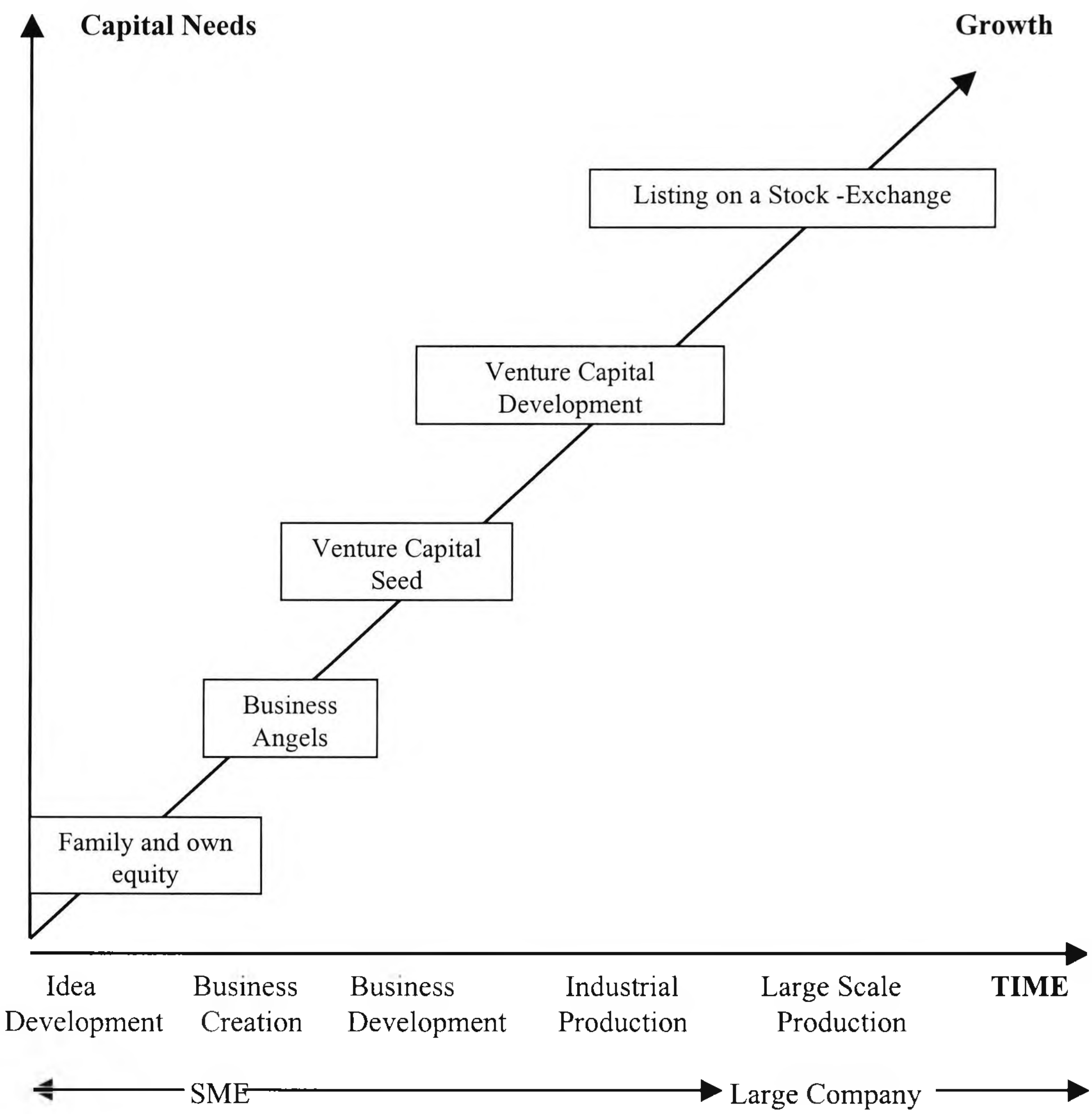

Figure 6.1: Company equity financing needs over time. Source: (CEC 1998).

The second type (venture capital and government institutes for the financing of innovation) is more risk oriented, wishes to generate returns from innovation and is more suitable for the provision of relatively "patient capital" in the form of equity, therefore more appropriate for SMEs and start-up companies.

6.5: The institutional investors' perspective when investing in high technology projects

The decision to provide large amounts of capital over a long period of time is not an easy one. It involves the evaluation of very fundamental questions of risk and uncertainty such as:

1. What are the involved difficulties and costs,
2. What the investment is for (and who is asking for it),
3. How big the involved risks are (to recover the investment and make a profit),
4. How soon the investment can be recovered and what is the exit rute,
5. How big profits can be and how soon can they be expected,
6. What is the commercial potential of the investment.

Hence, the decision to invest includes the evaluation of many parameters the most important of which are:

- *The market prospects* of the proposal, including considerations on distribution networks of products and services, market evaluation, customers' evaluations (what do they want to buy), marketing capabilities, the prospects of the market (does the project target an emerging market ?), industry or sector conditions and competition conditions, etc.,
- *Financial and credibility issues* such as the innovator's assets, resources, financial planning and own capital, the credibility of the innovator (size, previous history - if any, brand name), connection with established "names", guarantee schemes and others,
- *Management issues* such as business planning (vision, strategic aims, time-table and planning over time), operational effectiveness mechanisms and practices, organisational structures, supply mechanisms, human resources, management attitude and mentality etc.
- *Technological issues* such as assurance of technological expertise, technological feasibility over the proposed time, ability to meet technological milestones, technological and commercial potential of the technology under question, technological and commercial uncertainties directly related to technological factors, R&D capabilities, tangible and intangible technological assets, technology strategy and connection with business strategy etc.
- Offered monitoring, *supervision of the investment* ("voice") and *"exit"* mechanisms such as management places in the board of the innovator, compensatory duties, investment guarantee schemes, exit mechanisms etc.

On the basis of the estimation and examination of all the above mentioned parameters, institutional investors have to decide on "trade-offs" between anticipated profits, time horizons and involved risks (risk-return). The final decision (if they are going to be involved in a project and under what terms) depends on the outcome of a synergistic evaluation of the parameters of the investment and the investor's own perspective of acceptable levels of risk and strategic aims.

The following sections argue that investment decisions are primarily taken on the basis of economic, market, credibility, management and other non-technological considerations which place enabling technologies (e.g. structural materials technologies) with certain but distant or dispersed returns at a disadvantage. In addition, the following sections argue that when institutional investors take the decision to invest in technological innovation, materials technologies are not among their first preferences.

6.5.1: Capital for innovation: The Banks' perspective

According to Piatire (1984) during the early and middle 1980s, banks (in Europe and the US) were unwilling to take long-term risks with innovators. In earlier studies, Nickell (1978) also concluded that the cost of investment capital is an increasing function of the size of the investment but a decreasing function of the past profitability and wealth of the firm and its owners. This importance of the wealth of the owners (or more loosely firm size and credibility) was identified officially for the first time by Kalecki (1965) and 22 years later, Stoneman (1987) verified the point. When external resources are needed, Stoneman (1987) identified that:

- The cost of borrowing (debt) and the kind of investment will depend on the attitude to risk of the financiers. If it is not in line with society's general attitude to risk there may be a selective under or over-investment in technological advance and innovation[24].
- Large (and wealthy) firms with good track records (reputation and name) may borrow cheaply; small or new firms may pay dearly to borrow (Piatire 1984). The relative cost of finance may not, however, reflect the innovative level of the two groups, and this may imply sub optimality of resources allocation.

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[24] This is a crucial point; it implies that despite the general tendency towards medium to short term investments some technologies may attract long-term over-investment. This is quite clear in the case of technologies like biotechnology, telecommunication technologies and information technologies. However, much depends on market 'trends': In 1999 the biotechnology sector in the US and Europe is out of 'fashion' and all attention is focused on internet related stocks.

According to the above, it can be presumed that large firms sufficiently satisfy market and management considerations, while technological issues do not seem to have a critical influence on the investor's decision. These views, however, are at least ten years old and they belong to an era where the importance of technology and technological advance had just started to be appreciated in the financial and capital markets. Surprisingly, there is a huge gap in the literature covering the issues of how large commercial and investment banks take decisions to finance high technology projects, up to what extent they are involved and under what conditions they provide capital to innovators. Most of the information of how capital markets behave comes from the literature examining the behaviour and response of Venture Capitalists (VCs). Carr, Tomkins and Bayliss (1994) and Guild and Bachher (1996) suggest that similar to the above described conditions still apply. Banks still selected on the basis of industry and not technology and they clearly provide a preference[25] for high-technology services industries (e.g. telecommunications, software) or for life-science industries (e.g. pharmaceuticals) which provide certain and relative fast returns.

From the authors perspective, investment banks and VCs share many common characteristics and face many common problems in their effort to pick the optimal high-technology related investment opportunity.

6.5.2: Capital for innovation: The Venture capitalist's and other equity investors perspective

Venture capital is recognised as an important element for the finance of technological innovation and as a key element to job creation in the UK, the US and the EU (Brown 1998, CEC 1998). Brown (1998), based on a recent report prepared by the European Commission[26], stated that:

> "... in Europe, the conversion of new innovations into products, especially in high-technology areas, has been hampered because investors have been unwilling to take risks,... capital markets are too fragmented,... and there is too little support for start-ups. (...) The challenge for Europe is to create a strong venture capital industry and to orient venture capital to hi-tech risk (e.g. electronics, biotechnology, communications), early stage and start-up companies."

Venture capital is characterised by: (1) high degrees of capital mobility, (2) investment flows to the areas of greatest opportunity and return on investment (high growth areas), and (3) the development of specialised sources of venture capital

[25] See financial/economic press releases in the UK during the 1995-1998 period.

[26] See CEC (1998): '*Risk Capital – A key to Job Creation in the EU.*'

supply around both established financial centres and centres of high-technology industry. Venture capital offers equity to innovators and it is (theoretically) prepared to take higher risks when there is sufficient justification. However, the willingness to take higher risks is not necessarily in favour of long-term projects[27].

The important questions for high technology based innovators are (1) whether or not venture capital firms show a bias against or in favour of investing in technology-based, start-ups and, (2) under what decision making criteria venture capitalists and other equity investors evaluate technology based companies which are seeking early stages of financing (seed, start-up or first stages of growth, expansion or diversification).

With respect to the first question, evidence from the UK/EU and the US venture capital industry statistics indicates that American venture capital firms invest nearly three times as much finance into technology-based, start-up and early-stage investments as their UK/EU counterparts (CEC 1998). US venture capital firms are also more likely to invest at the earlier stages of investment, while the UK/EU industry has increasingly come to be dominated by management buy-outs and other later-stage, refinancing activities such as expansions of established firms (Murray and Lott 1995, CEC 1998, Green 1991). During the last three years however, this tendecy is changing as many examples of ventures in new technology start-ups have performed well in the UK/EU (e.g. the biotechnology related start-ups). This is changing again due to the underperformance of the biotechnology sector.

With respect to the second question, the answers are rather discouraging for high technology based innovators and technology based projects, while revealing significant weaknesses within the equity capital markets.

Wilson (1993) confirmed the results of a 1991 study (Green 1991) and pointed out that both in the UK/EU and in the US, venture capitalists which had invested, or were prepared to invest, in technology-based companies confirmed that technology projects had to meet more rigorous selection criteria than non-technology projects. In undertaking technology-based project evaluations, investors imposed higher investment return 'hurdle rates' at each stage of investment other than seed capital. In addition, Murray and Lott (1995) pointed out that technology-based projects in the UK were more frequently required to address minimum markets greater than the UK alone when compared to other investment categories. Surprisingly, no bias was found between the actions of generalist and technology specialist venture capitalist towards

[27] Nevertheless, investment in biotechnology in necessarily of a long term nature. What is important is the exit route, that is the ability of venture capitalists to sell after 5-7 years, following initial public offerings.

technology-based projects. The ratio of technology-based projects offered to technology-based projects accepted was similar for both groups (Murray & Lott 1995).

This "paradox" is easily explained by reviewing the decision making criteria currently used by equity investors to evaluate technology based companies which are seeking early stages of financing from institutional equity investors. Guild and Bachher (1996), analysed the group differences among decision making criteria used by Canadian equity investors (venture capitalist, business angels and public venture capital funds) to evaluate the business worthiness of some of their recent specific technology based business ventures. From a plethora of mentioned criteria, a priori assignment was given to the following five categories: (1) characteristics of the entrepreneur(s), (2) characteristics of the market targeted by the venture, (3) characteristics of the venture offering, (4) investor(s) requirements and (5) characteristics of the investment proposal from the venture to the investor(s). Guild and Bachher (1996) went on and identified specific key criteria as applied by these types of investors. None of them for any type of the three equity investors was technology specific or technology related. They were all based upon market, management, human resources, financial and business issues.

Older studies dedicated to international comparisons (e.g. Green 1991; Wilson 1993), confirm Guild and Bachher's findings for both sides of the Atlantic.

Evidence, however, from the Far East can tell a different story. According to Hurry et. al. (1992), the strategic logic of Japanese high-technology venture capital investment, reveals the existence of an implicit call option, or "shadow option", on new technology. This option is exercised by further simultaneous investment in product development, manufacturing and distribution after careful consideration of the technological issues involved. In Taiwan, venture capitalists generally prefer financing ventures at the development stage but about one-fifth of their funds goes to the start-ups. The initial screening of ventures is based on the nature of the industry (which is clearly technology connected), and the five most important criteria for the evaluation of the ventures which are: (1) return on investment, (2) market need for product, (3) *the venture team's technical skills*, (4) the potential market growth and (5) the liquidity of the investment (Pandey and Jang 1996).

6.5.3: Business Angels

Business Angels are private individuals who invest directly in new and growing unquoted business (CEC 1998). They usually provide finance in return of an equity stake in the business, but may also provide other long-term finance. This capital can complement the venture capital industry by providing smaller amounts of finance at an earlier stage than most venture capital firms are able to invest (CEC 1998). Business angel networks provide a channel of communication between private venture capital investors and entrepreneurs seeking risk capital. Their operation modes, when it comes to the evaluation of high-technology proposals are very similar to venture capital approaches (Mason & Harrison 1997; Guild & Bachher 1996) so they will not attract further attention here.

6.6: Why do institutional investors tend to be short termists ?

Boekholt & Fahrenkrog (1994) identified that in the early 1990s both debt and equity investors in the EU had the tendency to be risk evasive and concentrate their investment in short to medium term technological projects of proven financial or equity value such as business expansion and replacement equity for established technologies rather than investing in high-tech sectors (in 1992 only 16% of total EU of investment was in high-tech sectors). Much earlier, Leland and Pyle (1977) argued that when investors find it difficult to evaluate the quality or the potential of a project they are likely to treat low-risk, short-term projects more favourably than high-risk, long-term projects (e.g. processing improvements, well-known products, incremental improvements of well-understood technologies). The inability or difficulty to evaluate the quality and the potential of a proposal has many origins. Some of them are:

Risk aversion: short term projects with immediately visible results (usually cost reduction) are favoured by both investors and established innovators; process innovation prevails over new products innovation.

Information asymmetries: Zantout and Tsetsekos (1994) suggest that for competitive and strategic reasons, firms may not be willing to share their R&D plans or progress with outsiders. Therefore any signal about future pay-offs of R&D that the firm can send is unlikely to be accurate. Given these information asymmetries investors cannot accurately distinguish between high and low quality future opportunities, thus complex and/or long-term projects are more likely to be avoided making the externally generated cash-flow more available for medium to short-term[28].

During the last 10 years surveys on innovation investments have shown that the expenditures of firms are increasingly intangible and knowledge based (e.g. human resources, organisation skills, information networks, use of external sources of expertise). The effect is that investors are in increasing difficulty to assess the value of the firms assets and their commercial prospects. The challenge of evaluating intangible assets is very similar to the challenge of evaluating and contracting to provide technological information. *Technological Information* (**TI**) which includes much of the knowledge based intangible assets and the "know - how" methodologies, is an unusual commodity in four ways:

1. TI is difficult to be counted and valued; conventional indicators, such as patents and citations, hardly indicate value.
2. To value TI, it may be necessary to "give away the secret." This danger, despite nondisclosure agreements, inhibits efforts to market TI.
3. To prove its value, TI is often bundled into complete products, such as a computer chip or a pharmaceutical product. Efficient exchange, by contrast, would involve merely the raw information.
4. Sellers' or innovator's superior knowledge about TI's value make buyers or investors wary of overpaying.

These objective difficulties affect the way TI is produced or evaluated, encouraging self-reliance, while inefficient contracts or investment deals are often designed to secure rents or assets from TI. This can either be an advantage or be indifferent to large firms, however, it has a negative effect on small research and development firms. From the investor's perspective intangible TI is the asset most difficult to evaluate, but in many cases it includes a large portion of the value of a technology based project. Better information flow and the development and diffusion of technology rating and evaluation methodologies are a promising approach in facilitating the production and spread of TI. Source: Author based on Zeckhauser, R. (1996): '*The Challenge of Contracting for Technological Information*'. Proceedings of The National Academy of Sciences of The United States of America, Vol.93, No.23, pp. 12743-12748.

Box 6.1: The challenge of evaluating Technological Information (TI)

Technological Information (TI) evaluation difficulties: all types of investors (even specialised venture capitalists) have difficulties in evaluating technological information and other related *intangibilities* (**see Box 6.1**).

Lack of reliable rating, evaluation and audit mechanisms: reliable "codes of practice" and methodologies for the *evaluation and rating* of technologies with respect to both their technological and business potential / risks are still to be developed and diffused. Additionally, best practice *in audit* methodologies is still to be developed and diffused (Boekholt & Fahrenkrog 1994).

Lack of balance (or fear for lack of balance) between finance management and technological skills: Chapters 4 and 5 argued that the right balance in the

[28] Jacobson & Aaker (1993) argue that the extent of information asymmetry might be different in the US, Japan, and E.U. countries. This suggests a reason for inter country differences in the effect of externally generated cash flow for R&D and the differences in the attitude of large institutional investors.

technology/finance/management triangle is essential for the design and implementation of complex technological innovation projects. It is also vital for high-tech start-ups and SMEs. Some of the most spectacular investment failures in the software and biotechnology sectors have their origins in the lack of appreciation and understanding of new technology requirements from venture capital representatives, and, of management/finance issues from scientists (see The Times and Financial Times: press releases April-May 1998). Painful experience may contribute to increased risk aversion.

However, the tendency for risk aversion does not affect some technological fields (e.g. superconductors, biotechnology) as much as others, despite their long-term nature or the involved uncertainties. Clearly some technologies attract more capital than others. The question is why and if materials are included.

6.7: Why do some technologies attract more capital?

Why do some technologies attract more capital (e.g. biotechnology) despite their long-term nature and their high levels of uncertainty? Some possible explanations are:

Lack of expertise or discriminative expertise: Moody (1989) found that investment analysts in the City varied greatly among sectors in their qualifications. For example, the large majority of those concerned with electronics, communications, chemicals and pharmaceuticals (note the knowledge *connection* with the biotechnology industry) had a relevant technical qualification while most of those concerned other engineering and science fields (e.g. materials technologies, heavy manufacturing technologies) did not! Thus, a clear picture emerges of the City's understanding and support for innovative endeavours in some areas and its lack of understanding and thus support for others.

High-returns expectations: Due to information asymmetries innovation expectations for some technological fields run high. For some of them there is fair justification while for others is only pure enthusiasm. For example, telecommunications and information technologies justify the high expectations. Superconductors, however, (an advanced materials technology) attracted too much capital in the US out of pure premature enthusiasm[29].

[29] It is a typical case where basic research results create a climate of euphoria. But, in materials, basic research can rarely be translated directly into a product. In contrast, basic research results in biotechnology also attract heavy investment because research in the biotechnology field can be directly translated into real product patents.

Technology diffusion reasons: If a new technology and the related products and services are to be profitable, they must be diffused rapidly into the market. Rapid diffusion of superior technology requires a competitive selection environment which is open to change, and which distributes profits not only according to the technological superiority but also according to the relative economic superiority of the competitive technologies (Metcalf 1991). From the investor's viewpoint the efficient operation of the profit mechanism is crucial. Some technologies and projects like software, multimedia, high-tech services meet these requirements while others (e.g. organic computers) do not.

Technological, product or services compatibility: In connection with the issue of the profit mechanism is the issue of compatibility. The more compatible a technology is with the industry / market it targets the more possible it is to attract capital. For example, incremental improvements, say, in synthesis and processing are short to medium term projects with visible results and they are compatible with the established technologies and manufacturing lines. New materials on the other hand, may initiate radical changes in the manufacturing base or necessitate the simultaneous development of many other technologies/techniques elevating the levels of cost and risk.

The issue of basic human and social needs: Some technologies target basic human needs like the need to communicate and the need to live a long and healthy life. This may explain why, say, the telecommunications and the biotechnology-health sector attract high levels of investment despite the high levels of the involved uncertainty. On the other hand, new heavy industrial technologies or infrastructure technologies do not enjoy similar understanding or social awareness and acceptance because they have limited or "invisible" markets or very long commercialisation times, or because they are socially unwelcome (e.g. nuclear technologies).

Reasons of 'fashion or trend': "Trendy" technologies are identified in which investment is justified by public opinion (e.g. environmental technologies), social need (e.g. public health) or market speculation (e.g. internet – related investments).

In view of the above, the kind of technologies which are more likely to suffer from under-investment are those with complex nature and implications, "invisible" results, difficult to protect results, and / or slow diffusion rates. These technologies combine three drawbacks:

1. They involve high levels of complexity and they require the involvement of many parties (e.g. materials necessitate multi-disciplinary approaches) and expensive equipment which can be out of the capabilities of venture capital.

2. Returns may be too distant and they may generate potentially uncontrollable spin-offs which makes these technologies un-attractive for banks.
3. They may not be socially acceptable (for any reason) or regarded as purely the responsibility of industry to attract government aid.

These reasons exclude many groups of 'invisible' and / or concealed generic technologies which simply enable many other technologies to exist[30]. In the materials case, almost all structural materials technologies and the majority of functional materials technologies (apart from few cases such as the superconductors case), have these drawbacks. They are regard to be very complex, multi-disciplinary and expensive. Hence they suffer from under-investment[31].

6.8: Discussion and recommendations on the institutional investors' perspective when investing in high-tech projects

By combining the findings of the two last sections it is apparent that there is a serious problem of perceptions and a need for reliable technology rating/evaluating methodologies which may have its origins in inability to fully understand and integrate technology/management/finance principles.

With respect to the investor's perception of the potential profitability of a technology there is a rather odd paradox: while evidence suggests that investors can distinguish which technology can be rapidly commercialised, their final decisions are primarily based on managerial, organisational, marketing and financial criteria. Technological parameters and characteristics (which mainly define the environment of the technology under examination) do not seem to be of critical importance. Apart from risk and profitability reasons, a possible explanation is that investors heavily rely for the technological and commercial potentials and limitations of a technology/project on outsourcing expertise. But outsourcing expertise provides one-off opinion, not integrated, continuous assessment of a project and does not build-in "know-how" on evaluating opportunities and risks of technological projects. Moreover, the outsourcing expertise, if it is a consultancy agency, can provide sound opinions, most likely for well-established, well-registered technologies and not emerging

[30] See also Patel and Pavitt (1994). '*The Continuing, Widespread (And Neglected) Importance of Improvements in Mechanical Technologies*'. Research Policy, Vol.23, no.5, pp.533-545.

[31] In support of the thesis arguments, functional materials were characterised by the UK Technology Foresight Programme as the major (materials) drivers for "new business creation" (DTI 1995). However, the new £240 million fund in support of venture capital announced by Chancellor of the Exchequer in 1998 targeted computers, telecommunications, biotechnology and electronics. It did NOT include materials technologies.

technologies where companies have every interest to keep a cover of secrecy (see above: information asymmetries).

As a result investors miss the opportunity to understand that in a growing number of technologies, management, finance, market and organisational characteristics (the characteristics they look upon to decide) are inextricably connected with the "hard-core" technological characteristics and requirements of each technology. In many cases, business choices are restricted or even dictated by the "hard-core" technological characteristics (see for example the materials case in chapters 2-5).

By identifying the necessity for reliable evaluation and rating mechanisms for the technological and business potentials and limitations of technological projects, a joint Dutch and Belgian government initiative has brought together a major investment bank, technology organisations and government funding bodies in a frame-work called *The Technology Rating System*. The expertise of these partners is combined to tackle perception problems and to produce a rating of a firm's managerial, technological and financial potential. If the firm or the innovation project is judged to have good prospects, the entrepreneur can use this rating to acquire private capital from banks or venture capitalists who emply this rating (Boekholt 1995).

Boekholt did not identify on what basis the technology rating systems was built. But Whelan (1988) identified that in technology strategy one may distinguish between base, critical and pacing / emerging technologies and direct the investment policy and R&D efforts according to their special characteristics.

From the author's outlook, institutional investors could develop in co-operation with technological and governmental institutions a technology rating system on the basis of the base, critical, pacing / emerging and generic technology typology as it is defined by Whelan and Dussauge, Hart and Ramanantsoa (1987) (see Annex 2.2). The concept of this typology and classification is based upon the concept of technological and innovation potential versus the involved limitations, and it can be universally applied to rate all types and groups of technologies. The two parameters which would first be evaluated are technological / commercial uncertainty (will it ever become a product and what are the market prospects) versus future applications and commercial potential. According to **Figure 6.2** we have:

Position 1: base technologies and process innovation have low technological uncertainty but low opportunities for high exploitation because they are saturated areas or the marginal profits have reached their limits.

Position 2: Critical technologies are well-registered technologies which have not exhausted their technological and applications potential. They have the highest commercial potential with relatively low technological risks. Similarly, base technologies fusion involves relatively low technological uncertainties and provides the opportunity for many new products.

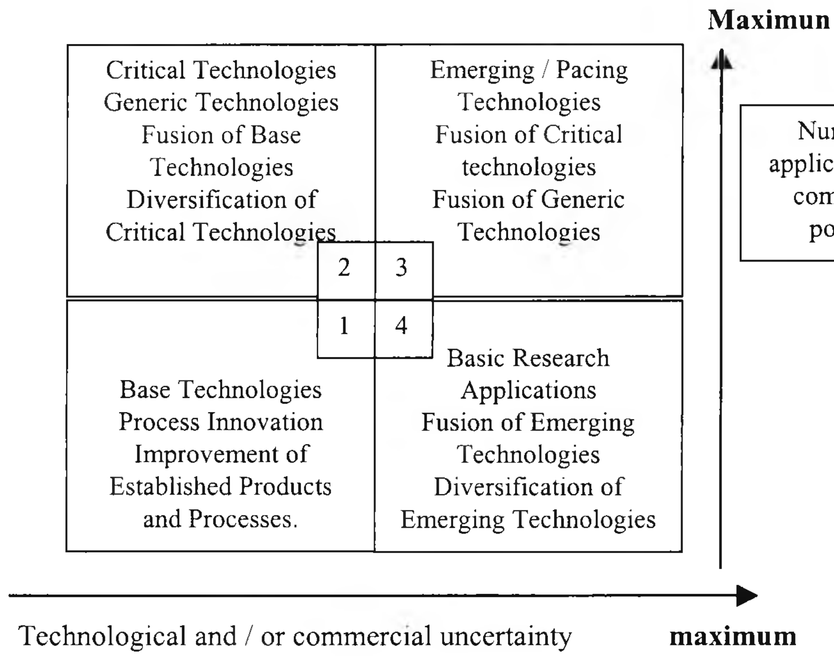


Figure 6.2: Technology rating system for the finance of innovation (Source: Author 1999).

Position 3: Emerging technologies and fusion of critical technologies are the source of the future competencies. Products and markets are visible and expected to be massive but there are many technological and commercialisation loopholes to be closed.

Position 4: Basic research applications (e.g. bio-computers) and fusion - diversification of emerging technologies. Technological uncertainties are high, while commercial and product applications prospects are not clearly visible and there is great uncertainty of the market conditions or the social acceptance of these technologies (e.g. cloning of animal and human DNA).

It should also be highlighted that the nature of technology not only defines the required sums, but it also sets the overall time framework and has a large impact on how precisely the capital will be used and *in what time scale*. For example, as identified in Chapter 2, functional materials require longer time horizons (thus more capital) during the design and prototype development stages while structural materials for performance-demanding applications require longer time horizons during properties and performance testing and evaluation. Similar requirements apply to most technologies. Many institutional investors fail to see this point, making the wrong sums of capital available at the wrong time.

6.9: Government agencies for the financial support of technological innovation

The previous sections indicated that there is a shortage of funding for many high technology innovators. The liberalisation and globalisation of markets has a positive effect on the process of securing capital for innovation, however, only for those who can access this capital. Large firms and not SMEs make the most of it (OECD 1995). The shortage of capital availability especially for SMEs can be explained by the uncertainty associated with such ventures, uncertainty which is magnified in the case of high-technology firms and high-tech start-ups. This uncertainty has its origins in a perception and information gap (both technological and commercial) which is exacerbated by an asymmetry of interest between the founders of a firm (industry in general) and private sector sources of finance. This asymmetry of interests is enlarged by an asymmetry of understanding on technological issues, by perception asymmetries of both sides, and by a huge gap in technology rating and investment audit methodologies. As a result, entire technological fields, and thus industrial sectors, may suffer from a shortage of privately motivated funding for innovation.

When these technologies or industrial sectors are of critical importance for competitive and industrial advance, the government may take direct or indirect action to provide finance for innovative industrial development or for high technology SMEs when banks and other private institutions are unwilling to do so. There are two basic forms this action can take: (1) the formation of public agencies with the aim to provide (or secure and channel) capital in support of large scale high-technology industrial activities and (2) the formation of public agencies with the aim to provide (or secure and channel) capital for high technology innovation in SMEs (Moore and Garnsey 1993).

1) Support of large scale high technology industrial activities. This policy is employed by many countries around the world (e.g. South Korea, Japan, Greece, France, Italy, Portugal, Spain). It includes the engagement of a number of public investment or commercial banks into the framework of a national industrial policy. Based upon general or specific guidelines set by the government, investment or commercial banks provide a battery of guarantee schemes and loans for large scale technological innovation projects. The state or the banks get, in the form of equity, a stake in the investment and usually participate in a controlling mechanism in the investment. An

alternative form of action is the formation of a public agency aiming to secure and channel capital by both domestic and international capital markets or funds to high technology industrial development projects[32].

A financing arrangement known as stock warrant off-balance-sheet research and development (SWORD) has been used recently in the US biotechnology industry to finance innovation. Innovation in the biotechnology sector is very risky because of the uncertainty about the commercial viability and regulatory approval of new products and technologies, while biotechnology firms are so small that they cannot diversify this risk internally across projects, and conventional internal financing of innovation is generally not possible because biotech firms tend to be lacking in both profitability and cash resources. Since a SWORD is offered to the investment public, the innovation risk can be diversified across many investors and their portfolios. SWORD can promote innovation in a manner not possible when more conventional financial management techniques are used because a SWORD structures the innovation as a real option. While conventional capital budgeting is like an ex ante commitment to the untested technology, a SWORD's license option agreement, which is the real option, permits the commitment to be made ex-post. A SWORD provides a biotech firm with greater control over the developed technology and its own future survival. It has a niche as a special, all-equity form of project financing for R&D that is nearing the implementation stage.

SWORD was developed for biotechnology firms but SWORD financing is likely to be successful in other situations, such as when product development is technical in nature, or obtaining financing is difficult because of the large risk of the product development, or because of firm size. The contractual relations imbedded in a SWORD are likely to be most important when control over manufacturing and marketing rights is central to the firm's future performance.

Source: Solt, M.E. (1993): '*SWORD Financing of Innovation in the Biotechnology Industry'*. Financial Management, Vol.22, No.2, pp.173-187.

Box 6.2: The SWORD financing arrangement for the support of Biotechnology firms in the USA.

2) Support for high technology innovation in SMEs. This type of policy has various mandates to assist high technology SMEs to raise capital during their development stages, some of them specifically for R&D expenses. It usually includes the establishment of specialised agencies and the channelling through them of substantial venture capital funds to support SMEs in pre-selected high-technology fields[33].

The establishment of these agencies is based upon the realisation that SMEs face more obstacles to their effort to secure capital for innovation, and to the recognition that apart from capital, SMEs need support in many other forms (e.g. management and organisation consultancy, intelligence gathering and consultation on international technological developments and others). Good examples are the Small Firms Merit Awards for Research and Technology (SMART) government scheme in the UK, the PRAXIS group for technological innovation in Greece (see chapter 7 and 8) and the

[32] A typical case of this mechanism is The Hellenic Centre for Investment in Greece (ELKE) which has the mandate to attract foreign investment and promote international alliances with Greek companies (see chapter 7 and 8).

[33] In the UK for example, G.Brown, Chancellor of the Exchequer announced the availability of three new venture capital funds totalling £ 240 million to support SMEs, particularly in high-tech sectors such as computers, biotechnology, electronics and communications.

Stock Warrant Off-balance-sheet Research and Development (SWORD) financing arrangement for the biotechnology sector in the USA (see **Box 6.2**).

In brief, the role of the state in regulating and directing financial resources to technologies and sectors of critical industrial and national interest still remains strong and, according to OECD (1995), for small countries is more important and necessary than ever.

6.10: How Do Firms Cope?

Capital markets are influenced by both governmental measures and by the behaviour of private sources of capital. So far it is (or they believe it is) to their interest to adopt a cautious approach to long-term technological innovation and favour short to medium term projects. Within this environment, corporate management is called on to compromise the pressure between increasing demands for R&D and innovation expenditures, internal / external financial and management pressures and year to year performance requirements. Kamien and Schwartz (1978), state that "among the leading characteristics commonly associated with industrial R&D, one of the most prominent is the necessity of it to be virtually financed internally from a firm's current profits and accumulated funds[34]". However, the issue of corporate resources allocation for R&D is directly connected with the management's perspectives and the type of internal controls for evaluating corporate management performance.

The following sections argue that strategic controls when combined with financial controls, favour the allocation of corporate resources to both short and long-term R&D activities, and hence, they are the most appropriate to support materials innovations. However, the application of financial criteria (e.g. net present value) controls alone, discourage (or even inhibit) the allocation of corporate resources to long-term projects and technological innovation. Nevertheless, corporations are 'living', interacting organisms subjected to constant influences from their environment (including the national system for financing innovation). According to the findings of a recent OECD study[35], it is arguable that some national systems of financing innovation favour the development of financial controls for monitoring and evaluating corporate management performance, while some others favour the

[34] While it would be inappropriate to view the firm as having access to separate sources of finance for "total" R&D and for the sub-total "physical" R&D, most of the attention is focused on the sources for the "finance for R&D" in a general context, ignoring the inter-relationship of the two factors (Himmelberg & Petersen 1994, Link & Tassey 1993).

[35] OECD (1995). '*National Systems for Financing Innovation*'. Paris

development of both strategic and financial controls for the evaluation of corporate management performance.

6.10.1: Large Firms and the issue of corporate resources allocation for R&D

A very brief overview of the resources of the firm is provided by **Table 6.2** which shows a simple classification of the principal categories of firm's resources. Note that the more technology-intensive a firm is, the larger the share of the intangible value of its resources when it wants to negotiate for external resources. Table 6.2, also applies for SMEs in a much smaller scale.

Resource	Main Characteristics	Key Indicators
Financial resources	The firm borrowing capacity and its internal funds generation determine its investment capacity and its cyclical resilience	Debt/equity ratio Ratio of net cash to capital expenditure Credit rating. Annual sales or profits Technology pay-ofs
Physical resources	The size, location, technical sophistication, and flexibility of plant and equipment; location and alternative users for land and buildings; reserves of raw materials constrain the firm's set of production possibilities and determine the potential for coat and quality advantage.	Resale values of fixed assets. Vintage of capital equipment Scale of plants. Alternative uses of fixed assets.
Human resources	The training and expertise of employees determine the skills available to the firm. The adaptaility of employees determines the strategic flexibility of the firm. The commitment and loyalty of employees determines the firm's ability to maintain competitive advantage.	Educational, technical, professional qualifications of employees. Pays rates relative to industry average.
Technological resources	Stock of technology including proprietary technology (patents, copyrights, trade secrets) and expertise in its application of know-how. Resources for innovation: research facilities, technical and scientific employees.	Number and significance of patents. Revenue from patent licenses. R &D staff as a percentage total employment.
Reputation	Reputation with customers through the ownership of brands, established relationships with customers, the association of the firm's products with quality, reliability , etc. The reputation of the company with the suppliers of components, finance, labor services, and other inputs.	Brand recognition. Price-premium over competing brands. Percentage of repeat buying. Objective measures of product performance. Level and consistency of company performance.

Table 6.2: Classification of the principle categories of the firm's resources. (Source: Elomiaty 1997).

Large multinational firms primarily finance strategic R&D from internally raised capital and internal financial resources (OECD 1996a, Himmelberg & Petersen 1994). Mayer (1990), comparing the sources of capital for R&D for a number of OECD countries around the world and for the period of 1971-1985 concluded that capital markets were not significant net contributors of corporate R&D capital for any of the investigated countries. Large firms typically generate much more internal cash-flow than they need for R&D investment purposes and it is unlikely that existing financial constraints would have any significant effect on the finance of *strategically* important R&D projects (Himmelberg & Petersen 1994).

Capital markets and institutional investors come in only as occasional supporting mechanisms; large firms use external capital markets as a source of capital when internal resources are insufficient and for industrial rather than technological activities such as large scale expansions, acquisition of real assets, large scale machinery and infrastructure replacement and so on[36]. Thus, large firms mainly depend on internally generated resources for the finance of sensitive R&D projects.

Management perspectives are a major determinant on the issue of corporate resources allocation for R&D (Demirag 1995). The critical question on the decision making level, is which internal and external forces and parameters are driving the internal capital allocation procedures of the firm towards or away from long-term R&D and other innovation projects. The following is a brief analysis of internal and external factors in favour of or against long-term R&D investments.

<u>Internal influences against long-term R&D investments</u>

** Evaluation of management performance on the basis of financial indicators. The decentralised structure of many firms, and the emphasis on financial controls and standardised, accounting-based, impersonal reporting mechanisms which limits information exchange and co-operation between line and upper management has been extensively highlighted as primary source of short termism (Cosh et.al 1990). A company under financial control can be best described as a company where the headquarters is dominated by a strong finance function and underneath there are layers of general management each monitored by its own finance activity and

[36] Oakey's views (1984) on the use of bank finance at such low levels are as follows:
"Innovative firms in need of investment finance often do not approach banks because they feel that their application will be refused, with some loss of face... . At a practical level, way beyond their public protestations that investment in high technology firms is a fundamental objective, banks are often wary of innovative high technology firms because they find the technical (and economic) potential of a proposed product development difficult to judge, while all the financial elements available to accountancy evaluators, reveal a poor financial position brought on by the cost of R&D and its detrimental effect on short -term or even medium term profits. In such circumstances firms by pass banks and seek other sources of capital".

emphasised profit responsibility right down to the lowest level (Goold and Cambell 1987). These companies primarily focus on annual profit targets. Failure to deliver the promised figures can lead to management changes. Within this frame, Hoskisson et. al (1993) argue that the application of internal financial controls in large industrial firms affects their risk orientation and thus their decisions to invest in R&D. Division managers' incentive compensation based on financial performance is negatively related to risk taking as measured by R&D intensity. In the same vein, Richards and Tylecote (1995) identified that accounting-based rules and structures tend to subvert long-term and even sometimes medium-term R&D strategies.

** Product-based diversification. The use of financial controls becomes more common as firms diversify (Baysinger & Hoskisson 1989). In highly *product-diversified* firms, corporate executives must not only decentralise operating authority to divisions, but they also have difficulties in emploing strategic criteria to evaluate division managers. As a result, they begin to emphasise financial controls.

** Interpretation of external signals. It is argued that capital market pressures are increasingly directed towards short-term performance evaluation of mangers and their operations (Porter (1992), Demirag (1995)). Demirag argues that short-term pressures perceived by the managers to emanate from financial institutions are causing firms to retain or adopt "Financial Control" management styles. Therefore, the "message" financial and capital markets and institutional investors deliver is of critical importance (see external influences).

Internal influences in favour of long-term R&D investments

** Reasons of technological necessity. The special characteristics and the complex nature of many technological fields necessitate the implementations of strategic controls and long-term R&D investments. Especially in the case of emerging and generic technologies (e.g materials) which require a long "incubation" time and with relative invisible but certain future benefits, the substitution of strategic controls with financial short-term controls can be catastrophic for future competitiveness. The Alcoa-Audi collaboration for example, which produced the aluminium frame car, would be impossible to efficiently manage under unidirectional financial control evaluation mechanisms.

** Technology-based diversification. Technology-based diversification multiplies the needs for understanding of the involved technologies (as opposed to product diversification). Since outsourcing cannot in itself create efficient, long-term core competencies, firms are obliged to invest in developing these competencies internally. Therefore they invest in technology development and the expansion/deepening of their knowledge base.

** Involvement of share holders. Demirag (1995) argues that large size institutional investors have the resources to understand and analyse in depth the nature and potential of their investment and "voice" their views in corporate affairs, putting pressure on managers, boards and even legislators. These tendencies for concentration of equity instead of cash have the tendency to inhibit short termism and bring stability and long-termism. This tendency is relatively new in the USA and UK but a common practice in Japan and Germany.

** Multi-disciplinary and co-operative "culture". Corporations committed to team-work and multidisciplinary approaches are more likely to suffer less from internal information asymmetries and highlight the adoption of strategic controls as a pre-requisite for the implementation of complex tasks.

*** Management training. A positive effect on the bias between strategic controls and financial controls results from the educational background of top management. Scherer & Huh (1992), after examing for profitability and the industrial fields in which 221 research-intensive U.S. companies operated, identified that over a 17 years span, having a science or engineering-educated leader is associated with more intensive and long-term support of R&D. *A positive interaction between technical and legal/finance education was also detected.* This education issue - directly connected with the perception of the investment analysts issue- was identified in chapter 5 during the discussion of materials education issues. Based upon Dennis and Chelsom's (1994) argument for the need to train management with curricula encompassing and integrating finance – technology – management principles, chapter 5 identified that many obstacles for materials strategies and their integration in technology and business strategies would have been solved if the management perception could foresee the full scale of inter-connections and implications involved. Here it is verified that similar qualifications can be of even more crucial importance because they can be used to optimally integrate two normally conflicting worlds: the world of finance (where the aim is short-term profit) and the world of technology (where the aim is long-term competitiveness).

<u>External influences</u>

Porter (1992) and then OECD (1995) identified that the external capital markets and the national financial systems have a direct impact on the forces driving the internal capital allocation procedures of US and other OECD countries companies. As in the case of internal influences, external influences can promote or inhibit the implementation of financial or strategic controls and therefore, influence the allocation of corporate resources in R&D.

According to OECD (1995) national financial systems are traditionally classified between two major groups (see **Table 6.3** as adopted from OECD 1995c):

- *Market-based systems* (typical representatives are the UK and the USA) in which financial security markets play a predominant role in supplying industry with external capital and which are notable for the separation between corporate ownership and control, and,
- *Credit-based systems* (typical examples are Germany and Japan) which give a much more important role to banks and other institutional investors both as financial channels and as partners in corporate management.

Some of the major points of the two systems are described below:

** Paterns of ownership. The pattern of ownership bears the imprint of the way industrial firms are managed, and in particular the degree and type of involvement of shareholders/financial players in firms' decisions regarding the internal utilisation of capital. In market-based systems, shareholders are numerous, irrelevant to each other, and short termist - thus companies are forced to concentrate on achieving measurable near-term results that will positively affect the shareholders current earnings. On the contrary, credit-based systems have an external capital system characterised by large, semi-permanent shareholders driven by a desire for both long-term appreciation and long-term relationships between investors and companies.

** Type of ownership. In market-based systems the stability of ownership is low, while the predominant shareholders are households (US) or non-bank financial institutions[37].

In market-based systems, institutional investors or shareholders under pressure are often blamed for putting inappropriate short-term pressures on management by their preference to "Exit" rather than "Voice", with their satisfaction or dissatisfaction mainly based on financial performance criteria (DTI 1990; Williams 1991). On the contrary, in credit-based systems stability of ownership is high and the predominant shareholders are financial institutions and industrial firms. As a result, extensive information of a company, its industry, and its long-term prospects is accumulated over time from both public and insider sources. Moreover, these shareholders prefer the "voice" rather than "exit" method of controlling their investment.

[37] Cosh et al. (1990) found that stock market pressures were directed towards short-term performance assessments and even institutional investors were becoming more short-term oriented, in particular when their investment portfolios *were externally managed*. These people have tremendous pressure and no knowledge or time to understand about high technology portfolios.

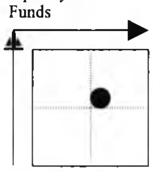
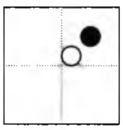
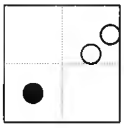
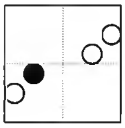
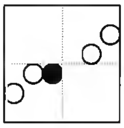
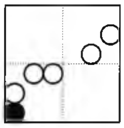
Major groupings		Market-based systems		Credit-based systems			(Pro memoria)
Sub-groupings and representative country		Weakly mediated United States	Strongly mediated United Kingdom	Global contractual governance Japan	Participatory governance Germany	Bank-centred governance France / Sweden	Relational banking Many developing countries
Industry financing Patterns	Dept / equity ratio	Relatively low		Relatively high			Very high
	Major financing instrument	Retained earnings and, to a lesser extend, bonds and new equity issues		Loans and retained earnings			Loans
	Nature of external financing	Increasing degree of liquidity of external Funds  Decreasing share of loans					
Prise mechanisms of capital allocation		Market process (including speculation) determine key prises		Markets are imperfectly cleared by prises: Traditionally government exercises significant influence on key prices and restores market balance through credit rationing; but this influence is continuously decreasing	Markets are imperfectly cleared by prises: The market power of major financial institutions gives them a significant influence on prices	Markets are imperfectly cleared by prises: Traditionally government exercises significant influence on key prices and restores market balance through credit rationing; but this influence is continuously decreasing	Price mechanisms are weak
Ownership patterns	Number of listed companies	Large (1.16 per billion $ of GDP)	Very large (1.84 per billion of GDP)	Relatively small (0.61 per billion of GDP)	Small (0.39 per billion of GDP)	Relatively small (0.68 (0.53) per billion of GDP)	Very small
	Dominant shareholders	Households	Non-bank financial institutions	Financial institutions and industrial firms	Industrial firms and banks	Financial institutions and industrial firms	Financial institutions and individuals
	Concentratio of ownership	Very low	Medium	Medium	High	High	Very high
	Stability of ownership	Low	Relatively low	High	Very high	High	Very high
	Extent of cross share-holding	Low		Large	Medium	Medium	Low
	Foreign ownership	Low but rapidly increasing	Significant	Very low	Significant	Significant	High
Patterns of monitoring	Main financial actors	Anonymous participants in the financial markets	Large non-bank financial institutions	Main banks	Universal banks	Universal and specialised investment banks	Banks
	Type of linkage	Unidimensional – Separation of ownership from control (monitor role is given only to share holders, which however may lack both the incentives and capabilities to exercise it)		Multidimensional with main bank as lender and shareholder, at the epicentre of the multy-layer network of factor providers (government may be an active or sleeping partner)	Multidimensional (universal banks play a key role through both control of large share of voting stock and lender's influence)	Multidimensional in the case of universal bank and unidimensional in the case of specialised investment banks (through equity)	Unidimensional through equity
	Basic monitoring principle	Direct outsider control by exit based on standardised criteria	Outsider control by exit (mediated by financial institutions) based on standardised criteria	Insider control by voice			Reverse control
	Mode of control – Type	Dispersed among specialised institutions		Exchange-centred with contingent strong bank influence	Bank-centred and participatory	Bank-centred	Private owners-centred
	Mode of control – Ex-ante	Investment banks, venture capitalists, underwriters etc.		At each stage, focus on supporting efficient exchange of information between participants into the network. At interim and ex-post stages, the control is shifted from management to bank only in case of financial difficulties.	The controlling power of the bank is counterbalanced by the presence of employees representatives on supervisory board.	Active monitoring by specialised investment banks. Looser involvement of universal banks	Banks are often owned by industrialists. Risk diversification is very limited.
	Mode of control – Interim	Security analysts, rating institutes, market arbitrageurs, etc.					
	Mode of control – Ex-post	Boards, take-over raiders, LBO associates, etc.					
Built-in capability to cope with	Acute adjustment problems	Leverage buy-out (LBO), bankruptcy procedures, Government-led bail-out, but difficult to implement	Same market instruments but less developed. Stronger tradition and institutional capabilities for government intervention.	Main bank-led restructuring. Well-proven procedures for activating government's role within the network to which belong the troubled firms.	Universal bank-led, but co-determined (employees' voice) restructuring. Government support in extreme cases.	Bank-led restructuring. Strong tradition of government intervention	
	High risk and uncertainty	Venture capital and other creative financial instruments. Large (defence related) to medium scale government support	Less developed venture capital Large (defence related) to medium scale government support	Intra-preneurship within the network. Rapid development of creative financial instruments. Medium-scale government support	Banks consortia. Diversification of large banks towards support of SME's creation and development Bank supported intra-preneurship in large firms. Medium scale government support	Bank consortia Government enterpreneurship and large scale support.	

Table 6.3 continuous

Major groupings	Market-based systems		Credit-based systems			(Pro memoria)
Sub-groupings and representative country	Weakly mediated United States	Strongly mediated United Kingdom	Global contractual governance Japan	Participatory governance Germany	Bank-centred governance France / Sweden	Relational banking Many developing countries
Emerging Trends (Globalisation and deregulation of financial markets promote international convergence in financing patterns)	In the 1980s increase in the dept to equity ratio reflecting a decrease in the relative cost of dept. In the 1990s, institutionalisation of stockholdings (increase in the share of stocks held by pension and mutual funds), and return to more active monitoring by some financial intermediates, especially pension funds		Diversification and internationalisation of available financial instruments. Decrease of dept to equity ratio in large firms which make greater use of security as financing instruments.	Decreased dependency of large firms on universal banks' loans through increase in self-financing. Correlative diversification of large banks' loans	Steady growth of the financial market Continuous decline in State ownership and influence on capital allocation	
Some critical issues	Short-termism, Problematic finance of intangibles, especially human capital. Venture capital market shows signs of decline Mixed record of Mergers & Acquisitions as a way to discipline usage of capital, especially when one considers their effect on R&D activities.		Deficiency in disciplining the usage of free cash flow – a fairly new problem in Japan—(to prevent it from being invested in projects with negative return) The efficiency of the dominant corporate governance system is debatable in certain types of activity (e.g. biotechnology, software) where seizing technological and commercial opportunities calls for more flexible organisational modes.	The dominant corporate governance system is weakened by the tendency for large firms to drift-away from banks financing and by the turbulence that the reunification creates on the labour market, which make co-determination more difficult Diversification of large banks towards small firms calls for a problematic adaptation of their assessment and monitoring procedures	State retreat from traditional areas of financial intervention has been a continuous but not always smooth process The French financial system, including government support, is still generally discriminating against small firms. Lack of venture capital or good substitutes.	

Table 6.3: National financial systems – A simplified typology. (Source: OECD 1995).

As a result, the incentives of the shareholders are more in line with those of the companies' management, which tend toward perpetuation of the enterprise over the long-term. Moreover, technology is more evaluated and appreciated during decision making. The fact for example, that firms in Japan with large debt ratios are likely to increase their investment in R&D expenditures suggests that financial distress costs are not a major determinant for Japanese companies (Bhagat & Welch 1995).

** Types of monitoring. In market-based systems the type of linkage between ownership and control is unidirectional and the mode of control is dispersed among specialised (financial in their majority) institutions. These arrangements favour the development of financial controls over strategic controls and limit the risk tolerances of corporations. On the contrary, in credit-based systems, the type of linkage between ownership and control is multi-dimentional, the power of financial institutions is balanced by corporate or industry representatives and emphasis is provided on efficient exchange of information.

According to the above, it is easy to see how the financial control style of evaluating management performance (or simply managing the corporation), if let alone, can inhibit spending on R&D for long-term projects by the pressures it generates internally. Firms perceiving short term pressures or under financial controls will respond according to their financial situation: when heavily profitable they may spend heavily on R&D but when marginally profitable or non-profitable, they will cut down the R&D expenses, viewing R&D spending as a luxury they cannot afford. This is a typical approach where R&D is viewed as an overhead or as a 'necessary evil' and as chapters 3 and 4 argued is *completely inappropriate* when corporations aim to gain competitive advantage through materials competencies or technological supremacy. To reverse the argument, materials technologies cannot be sufficiently supported by financial controls alone.

On the contrary, under strategic control rather than financial control, decisions are based upon the synergistic evaluation of many parameters, and companies evaluate divisional managers by criteria based on operational understanding of strategies proposed as well as criteria based on financial performance. The employment of long-term strategic control approaches *does not* exclude the employment of financial controls as "tools' to achieve operational effectiveness. But, as identified by Porter (1996), operational effectiveness (usually connected and measured by short to medium term financial performance) should not be confused with the overall business strategy, let alone substitute for it. Risk is minimised when operational effectiveness "serves" strategic aims, but should not substitute for them in the decision making process.

6.10.2: Small Medium Enterprises

High-technology start-ups and SMEs in the process of growth or expansion, because of capital market imperfections, are bound by financial constraints (Himmelberg & Petersen 1994, CEC 1998). As **Table 6.4** suggests, SMEs do not have many possibilities to raise internal capital for innovation and they have to rely on external sources like venture capital and business angels or government schemes and grants. However, the sections above have argued that the primary sources of external capital for SMEs have a preference for lower risks projects or for specific technological fields. According to OECD (1995), isolated SMEs suffer considerable handicaps in access to sources of finance, and the globalisation of financial markets makes this problem more acute. In addition, it should be stressed that, when available, start-up capital is only the initial requirement for a high-technology firm. Growth and expansion will depend on the availability of further finance. As **Figure 6.1** suggests, the continuation of financing from one stage of development to the next must be smooth and continuous. However, SMEs often find that when the stage of development changes, the sources of finance are likely to change, and it is during theses changes that the existence of the firm is in danger (CEC 1998).

According to both OECD (1995) and CEC (1998), a proposal for more effective support of SMEs could be that aid to individual SMEs should be incorporated within an overall strategy of support for innovation *networks* and industrial sectors/clusters.

Commercial Sources	**Non-commercial Sources**
Bank loans and overdrafts	Personal saving of proprietors
Finance secured on personal assets	Family and friends
Commercial mortgages	Local authorities
Factoring	EU loans and grants
Franchising	*Government loans, grants and other supporting schemes*
Flotation	Private sector supporting schemes
Leasing and hire purchase	
Direct advertising to attract private investment	
Venture Capital	
Business Angels	
Local Investment Networking Companies	
(Italics indicate major sources of external capital).	

Table 6.4: Sources of Small Business Finance (Source: OECD 1993).

This is the recognition of the fact that high-technology SMEs cannot survive individually in an aggressive environment but on the other hand they have a strategic role to play within this environment. To use materials-related SMEs as an example, chapter 4 argued that there is not much future for materials SMEs unless they relate (or network) their activities with a number of large materials producers or users. This proposal becomes more powerful through the findings of this chapter, and the proposal of sections 6.2&3 about a set of strategies for the support of innovation which aims to support individual companies not just as individual institutions but as members of an integrated innovation and industrial system.

6.11: Conclusions

- Both at corporate and at national level, the decision to pursue technological and business/economic competencies through the development and commercialisation of materials technologies (in general technological innovation), necessitates as a fundamental prerequisite the continuous and uninterrupted availability of financial resources for R&D and the diffusion of technological innovation.
- If companies and entrepreneurs are unable to raise internally sufficient resources for the finance of their innovation activities, then it is the role of capital markets and their major players (investment/commercial banks, venture capitalists, business angels and governmental agencies) to provide capital for technological innovation (either in the form of debt or equity). Given that a company's equity financing needs vary over time, ideally, (OECD 1995) capital markets must be able to cover these needs at all stages of a company's history.
- With respect to technological development and the availability of capital for technological innovation, the character and the efficiency of capital markets (or national financial systems) is largely defined by the characteristics and investment strategies of the institutional investors.
- According to the existing evidence, capital markets are not in favour of long-term materials technologies. Both investment banks and venture capital companies tend to over-invest in short to medium term projects and to heavily discriminate in technological fields by under-investing in many high technology areas (e.g. materials technologies, heavy machinery technologies) and over-investing in some others (e.g. electronics, telecommunications, biotechnology). For reasons based on perception (the aim is profit), information asymmetries, lack of understanding and a lack of reliable evaluation methodologies, they employ investment decision criteria based on credibility and on financial and managerial parameters rather than technological parameters. As a result, strategically important technologies (*most of materials technologies*) suffer from under-investment.
- Technology rating systems and methodologies, as well as reliable audit measures are still to be developed and diffused. A significant improvement can be achieved by a 'triangulation' (close collaborations) between financial institutions, technological institutions and governmental agencies. More holistic management perceptions able to understand the principles of both worlds can be used to optimally integrate two conflicting worlds: the worlds of finance and technology.
- The existing imperfections and resources allocation asymmetries in the capital markets justify a governmental involvement in an effort to support the finance of

technological innovation. Governmental activities in support of technological innovation aim either to reduce the cost of innovation or to support its development and diffusion into the national economies. In addition, government activities may take the form of direct resources allocation by making capital and supporting mechanisms available for venture capital activities in pre-selected areas of strategic importance.

- With respect to materials technologies, horizontal mechanisms and incentives such as tax credits create a favourable environment which in general encourages R&D investments but, if let alone, are superficial and insufficient because their generic character only superficially supports the development and diffusion of these technologies (see also section 6.3.2). The characteristics and the requirements of materials technologies necessitate the employment of more technology - or project - focused mechanisms which imitate the behaviour of institutional investors such as procurements, long-term loans and above all, long-term markets securitisation, especially for intensive final materials users.
- High technology large firms face less difficulties in attracting external capital for R&D but they rarely do so. Given that short-term financial control managerial styles, if let alone, inhibit investment in R&D and technological innovation (or are effective for very specific technological fields such as software development), the decision to pursue or develop materials competencies necessitates the adoption of long-term *strategic managerial controls*. However, the employment of long-term strategic control managerial approaches *does not* exclude the simultaneous and complementary employment of financial controls as "tools' to optimise operational effectiveness, in the context of an integrated technology and corporate strategy.
- High-tech SMEs (start-ups in particular) face more severe problems to attract or secure capital for R&D due to lack of size and resources. Government support for SMEs should aim to incorporate supporting measures for the finance of high-tech SMEs as a recognition of the fact that they hold a key role in efforts of national and industrial technological advancement and technological innovation.

Finally it has to be underlined that a national system of financing innovation is an integrated part of the national system for innovation. It should not be seen as separate and independent entity. Given that the characteristics of some national systems for financing innovation favour the finance of long-term technological innovation (an environment of patient shareholders for example), and provide good conditions for long-term R&D investments, whereas some others do not, the characteristics of a national system for financing innovation must be an important input in the design of a national materials and technology strategy.

CHAPTER 7: The Greek national system of innovation in the 1990's

7.0: Introduction and structure of the chapter

This chapter aims at providing a bridge between the analytical basis of chapters 2-6 and the discussion of the data and information obtained during the interviews with Greek institutions and firms on how they have responded to the challenge imposed by the advanced materials revolution. There are previous studies which identify and analyse the general characteristics, strengths and weakness of the Greek industrial system and the Greek national innovation system. Chapter 7 critically draws together the most relevant of these contributions with *some of the findings of the interviews* and the empirical data collection, and focuses on the elements and the general institutional and techno-economic characteristics of the Greek national innovation system which directly affect the Greek public and private sector *response to materials* and other emerging technologies.

As an introduction, the chapter includes two brief sections (section 7.1 and 7.2) which argue that in a global, technology-based, competitive environment the Greek economy has no other choice but move into the production and provision of high - technology, knowledge intensive products and services. Therefore, the creation and support of a strong and flexible national innovation system in support of the national industrial activities is of paramount importance.

Apart from the introduction, chapter 7 includes three distinctive but complementary themes: The first theme focuses on issues of industrial development. Section 7.3 examines, in brief, the circumstances of the Greek economy and industry focusing on issues of industrial development, its financing and the role of the Greek State in promoting industrial development and technological innovation. The second theme is dedicated to the identification of industrial sectors critical to the Greek economy and directly influenced by MSE technologies (section 7.4). Justification of why the selected sectors have been chosen for examination is also provided in section 7.4. The third theme of the chapter (section 7.5) provides a brief, albeit critical presentation of the national R&D and technological innovation system in Greece. The chapter ends with the identification and discussion of some important industrial and technology policy issues relevant to the design and implementation of both national and corporate materials strategies in Greece (sections 7.6 and 7.7). These provide the basis for posing and testing a number of working hypotheses in chapters 8, 9 and 10.

7.1: Globalisation and the emerging challenges for the Greek economy

In a global economy, economic competitiveness of a region or a country greatly depends on the ability to create and manage knowledge and technology for manufacturing and services exports (OECD 1996, Weiss 1993, Archibugi and Michie 1997). Two OECD reports (1994, 1996) underlined that trends in the performance of manufacturing and services are increasingly dominated by the continued evolution of the performance of science and technology which transform them into high-technology, knowledge-intensive industries. The continuous shift of industry towards knowledge-intensive forms also shifts economies to knowledge - based activities, and increasingly determines the levels of economic performance in terms of both productivity and international competitiveness.

Simultaneously, there is a shift in merchandised trade towards exchanges of intangibles such as quality, technological sophistication and know-how. For a wide range of products and services, an increasing portion of merchandised trade has a high level of *embodied technology*, frequently exceeding the tangible R&D investments. This reflects the increasingly intangible, service-like qualities and performance of products,[1] which although they can be physical goods, contain service like qualities the creation of which frequently requires significant amounts of invested R&D (OECD 1996).

Within this frame, for small economies like the Greek economy which become increasingly integrated into and exposed to global competition, the issue of specialisation in the international technological division of labour and the ability to create technology and knowledge for exports is of fundamental importance. It is well documented (Giannitsis (1984, 1991, 1993), Vaitsos and Giannitsis (1987), Kindis (1982, 1995), Politis (1992), Kalogirou (1993)) that Greece is neither in a position to continue to rely only upon "traditional" labour intensive industries nor merely upon future direct foreign investment (FDI) as happened during the 1960s and early 1970s[2]. Today the Greek industry and production systems are subjected to strong competitive pressures by a combination of low-cost products coming from the Far East or Middle East, Latin America or Eastern Europe and the high quality, high

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[1] Examples include aeroplanes *tailored* to the specifications of individual airlines, purpose tailored buildings, cars tailored to the national or individual needs, superior performance ships due to their electronics, etc.

[2] A recent OECD study (OECD 1995) on inward investment in the EU countries, showed that, in the period of 1986-1991, gross foreign direct investment inflows into Greece totalled less than 1% of GDP compared to 6% in Ireland, 3% in Portugal, and, 2% in Spain; UK attracted 45% out of the EU total, Greece less than 1%.

technology products originating from the West, the Far East and many newly industrialising countries[3] (NICs).

Given the size and capabilities of the Greek economy, Greece has few, if any other options but to concentrate all efforts on knowledge and technology - intensive industries and services or transform "traditional" sectors into high technology sectors on the basis of specialised know-how and technological expertise[4]. As argued in the first part of the thesis, the materials revolution and materials related competencies provide multiple opportunities for international technological and industrial competitiveness. In the case of Greece, the MR is both a threat and a challenge offering the opportunity to the Greek economy & industry to effectively respond and remain internationally competitive in a range of existing and future activities. Therefore, the questions of which materials technologies are suitable for Greece are of paramount importance.

7.2: National system(s) of innovation

In the literature (Dosi 1988, Freeman (1991, 1994), Lundvall (1988, 1992)), there are two different approaches to the issue of international competitiveness. The first approach is mainly based on trade theory and especially on the theme of comparative advantage (Dosi 1988). The second approach is based on the long term accumulation of know-how and technological capabilities and on technological specialisation (Lundvall 1992, Freeman 1994) leading to successful innovation.

Governments commit themselves to innovation policies because it is recognised that (technological) innovation is a key factor in economic growth. In the knowledge - based economy, (technological) innovation is driven by the interaction of products, services and technology producers and users in the continuous exchange of both codified and tacit knowledge. As shown in chapter 3, this interactive model has replaced the traditional linear model of innovation. Therefore, the configuration of a national system of innovation (NSI), which consists of the flows and interactions between industry, government and academia in the development of science and technology is an important economic determinant of competitiveness (OECD 1996).

[3] For Greece the emergence of many NICs as global competitors is of particular importance. They emerge as a new source of international competition based on a dynamic combination of technological competencies and relatively cheap labour targeting many of the "traditional" Greek exports (Giannitsis 1986) while they move rapidly to close opportunities and specialisation in areas and fields where Greece can gain a significant international role (e.g. photovoltaics, agro - biotechnology or advanced textile materials and textile technologies).

[4] E.g. Gianitsis 1991, GSRT 1992, Official position (1996)of the current Simitis administration.

The issue of the national system of innovation (NSI) has been analysed by the works and studies of Freeman (1987 and 1993), Lundvall (1988 and 1992) and Nelson (1988, 1993). The term innovation is broad and encompasses the process by which new products, services and manufacturing processes are generated and successfully applied in practice or get commercialised. The term "system" indicates a set of interacting policies, institutions, organisations and parameters whose combination determines innovation performance[5] (both in general terms and in terms of technological innovation). Therefore, a broad definition of a national system of innovation *involves the interaction of numerous aspects* of economic, industrial, and science / technology policies as expressed by the strategies of institutions such as the government, industry, academia, research institutions and services institutions. From a narrower point of view, it concerns the institutions and organisations, and the constant flow of information between them, involved in the production, diffusion, application and commercialisation of technological and other forms of knowledge and information (OECD 1996). As such, the success of enterprises, and of national economies as a whole, is ever more dependent upon their effectiveness in gathering and utilising knowledge. Strategic know-how and competencies are being developed interactively within the national innovation system and its elements and shared within sub-groups, clusters, and specialised networks. As such, the economy becomes a hierarchy of networks, driven by the acceleration in the rate of (technological) change and learning (OECD 1996). Therefore the existence of a functioning innovation system, is of paramount importance for any economy (Nelson 1993); small economies, like the Greek economy, in particular.

7.3: Background to Greek economic, industrial, and technological development

There are many studies[6] focusing on the history of the Greek economic, technological and industrial development, its weaknesses and some of its strengths. A number of studies have concentrated on discussing the Greek economic and industrial performance during the 1950s to late 1980s period, while more recent studies (published after 1990) have concentrated on discussing the Greek technological performance and national innovation system during the last 25 years.

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[5] For example, in France, the term "national innovation system" refers to a set of identifiable relationships between the political institutions, research organisations and business enterprises which has been produced over several decades" (Chesnais 1993).

[6] E.g. Giannitis (1984, 1991, 1993), Vaitsos and Giannitsis 1987, Mitsos 1989, Politis 1992, Korres 1995, Kalogirou (1991, 1992), Tsipouri 1993 and others.

Given the above mentioned studies the following sections extract characteristics which are of major importance to technology and science related issues *thereby providing the general framework in which materials technologies and strategies are (or have to be) developed and diffused.*

7.3.1: Elements of industrial, economic and technological development

A) Economic and industrial characteristics. Before WWII and up to the middle 1950s the Greek economy was dominated by the agricultural sector. After WWII, in the 1950s and early 1960s, most of the development efforts were concentrated on reconstruction and restoration of public and residential infrastructure and housing. The direct beneficiary was the construction industry, a sector with very old roots in the country. Most heavy industry was established in the 1960s and early 1970s through a series of five years plans drafted primarily with a view to produce import substitutes by taking advantage of the country's natural and mineral resources (exports were only a secondary consideration). The established industries included large food units, smelting, refining, chemicals, steel and aluminium production, cement and other structural ceramics and many manufacturing or assembly industries of machinery, transport equipment, construction related products (e.g. wires, pipes and structural steel industries) or even large scale manufacturing industries such as ship-building and defence related products.

Moreover, during the late 1960s and early 1970s a number of multinationals established a presence in Greece to secure access to this largely closed market and to take advantage of the then cheap labour. Note that it is usually these multinationals which have a vertically integrated character, that is, high-value added products. As a result, the economy was constantly growing and during the 1960 - 1970 decade Greek GDP growth was more than one and a half times the average of the now current 15 EU nations - 7.6% compared to 4.8% - while inflation remained below the, then, European average at 3.1% compared to 4.4%.

Simultaneously, domestic production was protected by high tariff barriers, quotas, governmental subsidies and orders and other administrative measures until the late 1980s. Export promoting measures[7] helped many producers to begin exporting and by the early 1980s there were 8000 registered exporting firms (ICAP 1995).

[7] Such as subsidising export manufactures on the basis of domestic value added. If the added value was less than 25% no subsidy was paid. If the added value was between 25% - 60% then subsidies ranging from 10% - 30% were paid - see Bank of Greece Currency Committee Resolution 1574/70.

Such protection created space for local companies but it hindered the beneficial effects of international competition. Even the export promoting policies had only short-term financial/economic effects and their general character failed to create long-term competencies. As Lyberaki and Travlos (1993) put it, in practice there were no pressing incentives to upgrade or invest in new technologies and products.

Another typical characteristic of Greek industry is its domination by SMEs. It is indicative that a National Statistics Service industrial census published in 1988, concluded that 92.5% of the enlisted manufacturing firms employed fewer than 10 people and only 0.5% employed more than 100. Hence, the overwhelming majority of Greek industry could not take advantage of economies of scale and regularly invest in new technologies and products.

B) Elements of technological development. Within this industrial environment, the adoption, development and diffusion of new technologies varied across different economic periods. In general, two periods are distinctive. The one prior to 1980 which was dominated by direct foreign (technological) investment, licensing agreements, and royalties, and the period after 1980 until today which is characterised by:

- intense efforts for creating domestic technological capabilities (especially after 1985 - see following sections),
- a constant decline (or stagnation) of inward foreign direct investment in technology and licensing (with the exception of the construction, telecommunications and other IT based services sectors), and,
- a trend of established foreign companies (intensive materials, components and services final users in particular such as Pirelli, Goodyear, Nissan) to leave Greece, which intensified after 1990.

With respect to domestic efforts, the small size of the internal market and the low demand for advanced products had, until recently, negatively affected the adoption or development of new technologies. In the absence of high - performance demand (that is demanding final users and customers) many attempts to increase the supply of research and technology were regarded as unnecessary luxury (Vaitsos and Giannitsis 1987, Tsipouri 1993). To make things worse, prior to the early 1980s, the low level of technological achievements of Greek industry (as measured by R&D expenditures, patents and balance of technology transfer and technology related royalties) was intensified by a serious neglect by the State of the national technological and science infrastructure and lack of central co-ordination and prioritisation in industrial and technological policies (Giannitsis 1993, Deniozos 1993). Support was provided indiscriminately in the form of horizontal macroeconomic measures and governmental subsidies (Lyberaki and Travlos 1993). Efforts were far too dispersed to have significant impacts, while there was very limited interface between public research and the productivity needs of the country (Kalogirou 1991, 1992).

On the other hand, since the early 1970s production costs were constantly on the increase while product quality and product innovation were only marginally improved (Skoulas and Kazis 1985) which strongly indicates that with respect to technological innovation private industry was also at fault. Lyberaki (1996) argues that Greek industries have no real excuse for their present technological difficulties. They knew competition would intensify from their exposure to global markets or European markets but, in the majority, did nothing to really prepare due to a negative combination of the management mentality of Greek firms and a lack of long-term vision and appropriate policies by the Greek government.

Until the late 1980s, and with very few exceptions, big companies and State controlled enterprises have relied for their technological needs on imported technologies notably incorporated in capital equipment. The few licensing agreements were related to the use of brand names rather than technologies (Kazis and Perrakis 1984). In industry, until the early 1990s, the funds allocated to R&D investments appear to be extremely limited mainly due to a general lack of confidence among Greek entrepreneurs in either the future of their individual companies (Skoulas and Kazis 1985, M1ST 1996), the prospects for economic development of a sector (Skoulas and Kazis 1985) or due to a lack of *awareness* of the necessity of the investment (Tsipouri 1993). In fact, many sectors of Greek industry failed to address the paramount issues of management of technology including issues of technological imitation and reverse engineering. The management of technology was circumstantial (management by coincidence), motivated by immediate rewards or it was ignored under the influence of the "invented-elsewhere syndrome" (Tsipouri 1993). Production capacity was the main issue, both in industry and for the government.

However, evidence shows that contrary to received wisdom, production capacity does not lead automatically to technological capacity in developing countries (Bell and Pavitt 1992). According to Tsipouri (1993), Giannitsis (1992) and Karageorgiou (1996) both the management of Greek industry and governmental officials failed to see this point and *concentrated all efforts in production capacity based on externally acquired technology*. As such, the simultaneous development of reverse engineering (imitative R&D) capabilities as a basic core competency during the early stages of the firms' development stages was totally neglected[8].

[8] Israel is a counter example of this. Their defence and other (mainly defence-related) industries are based on reverse engineering to a large extent.

C) Financial market characteristics. Until the beginning of the 1990s, Greek financial markets (banks in particular), were characterised by a high degree of State intervention and ownership (State groups controlled more than 80% of the commercial banks and 100% of the investment banks - Industrial Review 1991). The banking sector was highly regulated so as to fund public deficits and certain targeted sectors of the economy[9] (see below).

Venture capital was not institutionalised until 1988 and security markets (bonds and equities) were underdeveloped (OECD 1995). Moreover, capital controls and exchange restrictions isolated Greek financial markets from international capital markets and there was a clear-cut division of roles and activities between banks, insurance services and credit institutions (OECD 1995, Soumelis 1995). Lastly the financial system was regulated through interest rate and credit controls. Until 1987, both deposit and lending rates were fixed administratively and as a result of excessive State intervention, banks operating costs were among the highest in the OECD area (OECD 1995).

Since the early 1990s, financial markets in Greece entered a state of constant transition (OECD 1995). The reform of the Greek financial markets is progressing rapidly, transforming the system from one where everything that was not permitted was prohibited into one where the banking sector has the initiative and the Bank of Greece, the central bank, is increasingly consigned to a monitoring role. From being a system where lending was dominated by the concept of industrial, regional or agricultural development, it is today a system increasingly driven by Treasury and consumer credit operations-making money out of money (Industrial Review 1996).

The reform of the financial markets involved simultaneously a deregulation of the markets and a strengthening of the supervision of market participants. Until the end of 1995, deregulation had six major elements (most of them in line with EU directives): liberalisation of capital and exchange movements, the freeing of interest rates, end of credit controls, decompartmentalisation of financial intermediation, the creation of a vast market in Government securities and the introduction/ institutionalisation of new elements such as venture capital and investment promotion agencies.

[9] Obligatory investment rations were set restricting the freedom of banks to make loans and forcing specialised credit institutions to channel resources to privileged sectors such as the public sector or industrial - regional development projects. About tree-quarters of banks deposits were earmarked for loans to privileged borrowers (subsidised by the State), of which the State accounted for more than 55% in the second half of 1980s. In 1985, 10% of deposits served to finance SMEs, and 25% went to industrial development (Soumelis 1995).

On top of these changes, and since 1996 until to date, a "wave" of privatisation, mergers and acquisitions is radically changing the banking scene in Greece[10] and is expected to have a major impact on the banking sector investment policies and on financial markets which, nonetheless, is too recent for all its effects to have been felt.

7.3.2: The role of the Greek State in promoting industrial development

The role of the Greek State in the industrial development of Greece has taken many forms. The most important of them are either direct State involvement in the production and services sectors or the allocation of capital either in the form of market subsidies and procurement policies or in the form of loans and investments schemes heavily subsidised by the Greek government.

Direct involvement. Up to 1992, various estimates put State sector involvement in the total economy at between 60-70% of the GDP with monopolies and investments in, among other things, mining, utilities, transport, communications, defence, energy, the banking system services and even tourism. Through national industrial development schemes, the Greek State has significant holdings in many large manufacturing industries and through the State controlled commercial banks has hundreds of holdings in secondary industries[11]. The only major sectors in which the State does not have a significant presence are shipping and construction even though many sectors of the construction industry are practically "locked" within markets the Greek State provides and controls (e.g. the announcement and allocation of contracts for public works).

Market securitisation and procurements. The Greek State (including the public goods companies and the public enterprises) was and still is the largest market for products and services (one trillion drachma in 1985 or something between 15-25% of GDP per average annual base) and the largest employer in the Greek economy employing 17.4% of the available work force in 1989 (NSS 1992). In addition, in many industrial sectors, the small size or demand of the local markets and the lack of motives or substantial supporting mechanisms for exports, established the Greek State as the major customer of products and services.

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[10] In 1996 there were 55 banking institutions with nearly 85% of the market controlled by the public sector.

[11] Until 1994, the Greek State had total control and monopoly of all the public goods companies and in 1984, it owned 17 out of the 27 manufacturing companies with more than 1000 employees (ICAP 1994).

Kalogirou (1991,1992) and Zorbala (1992) pointed out that the subsidies, procurements, contracts and orders for goods and services of the public sector provided significant motives for the mobilisation of both domestic and international entepreneurship resulting in the establishment of new companies or even industrial sectors. But according to the same authors, until the early 1990s public contracts and procurements were not consciously perceived as tools for technological development. They were used only as instruments of industrial development or, especially in the late 1970s and early 1980s, as tools in the service of macroeconomic, social and political considerations (such as the notion of preserving employment by attempting to rescue ailing firms or sectors characterised as "sensitive" for the Greek economy). They were not used for creating strategic industrial and technological national champions. This point has been verified by the interviewed experts (e.g. PS1, PS2, PS4 1996) and receives further attention in chapter 8.

7.3.3: Elements of the financing of industrial development in Greece

The Greek private sector, did not have the large historically accumulated capital of western Europe. Most of the Greek large industrial units have their roots in development processes either financed by judicious re-investment of profits and reasonable borrowing (family business and SMEs which grew after the second and third generation) or, in the majority of the cases, by heavy borrowing or investment schemes supported or heavily subsidised by the Greek government (Lyberaki & Travlos 1993). Until the late 1970s the primary investor in industry has been either Foreign Direct Investment (FDI) or the State providing capital either directly or through State controlled investment and commercial banks (Tsoris 1984).

The State policy of allocation of funds was designed to create, enlarge or support productive sectors regarded as "sensitive" for the Greek economy[12]. Under these policies, both the commercial and especially the two national investment banks - the Hellenic Industrial Development Bank (ETVA) and the National Investment Bank for Industrial Development (ETEVA) -were used to finance industrial and technological development. For example, under the 1262/82 law, ETVA was forced to finance investments which had been turned down by commercial banks. Under this law, capital for industrial development schemes consisted (on average) of 36% subsidies,

[12] The idea involved the concept of creating "national champions" in the form of industrial sectors. The implementation of the idea, however, was at fault; 62% of the total manufacturing output including entire industrial sectors and all of their products were characterised as "sensitive" and began competing for subsidies and favourable treatment (Politis 1992).

36% loans and only 28% private or industrial participation (Lyberaki & Travlos 1993).

According to Demiris (1995) these policies had positive aspects because they forced the development of certain economic and industrial sectors which otherwise would have been deprived of funds. The funds would otherwise have gone to commerce and consumption. However, a serious weakness of the policy was its *implementation per se*. Funds were widely distributed, supervision and control mechanisms of the investment were insufficient, and in later stages people developed the notion that the loans and subsidies were a form of guarantee from the State and they took them - whether they needed them or not. They did not feel the need to become competitive through the use of borrowed money. Many problematic companies emerged from these investments and the banks (ETVA in particular) were lumbered with large - non - performing portfolios.

But the banks were also at fault. Even when they had decision making autonomy on capital allocation, or, especially, on the methods and management of the investment, they paid scant attention to the economic viability of companies and instead they took real collateral in the form of mortgages and participation in the form of equity positions in firms in order to protect their capital against inflation. They were looking not only for high returns but for capital gains although they seldom had pre-established *effective supervision and exit mechanisms* (Boumi 1996). When the collapse of many firms came in the 1980s, banks were left with large portfolios of non-performing loans and participation in potentially bankrupt firms. In the hope of recovering something, further loans were extended, compounding the problem. Even in 1995, firms over- indebted to State banks accounted for 80% of the losses made in the Greek industry (National Bank of Greece 1996).

During the last 7 years the State development banks have played a less important role because their state - subsidised capital resources have dried-up. The Hellenic Industrial Development Bank - ETVA - has lost the ability to make large independent investment decisions and is under EU supervision while administrating or directing funds of the Community Support Framework, some of them related to the Operational Programme for Industry (OPPI)[13]. The other investment bank, ETEVA, is working on developing a market for corporate bonds (B2 1996). Until recently (1996), this form of investment, widely used in other countries, was squeezed out of Greece because the bonds were taxed whereas the Treasury bills were not. On the other hand, commercial banks have reoriented their portfolios towards short-term (up to 2 years) lending.

[13] This programme receives further attention in Chapters 8.

Until recently they hesitated to take stocks and shares as collateral and they avoided participation and equity.

The private sector on the other hand, during the late 1980s began to look elsewhere for long-term capital resources: reinvestment of profits, rights issues, the stock market etc. Long-term loans in 1995-1996 accounted for only 10-20% of enterprise total borrowing (ETEVA 1995). Moreover, with the lifting of exchange controls and the liberation of capital markets many companies are taking short-term loans in foreign currencies. In 1995, 75% of all short-term loans were denominated in foreign currencies while 30% of the total recorded borrowing was denominated in foreign exchange (IOVE 1996).

7.3.4: Emerging industrial trends

The gradual but rapid exposure of Greece to open European and global markets during the early 1980's and the Single Market and Maastricht treaties in the 1990s lifted protection barriers, intensified competition and increased import penetration but it also enforced many "healthier and more rational" motives for product development based upon technological innovation. Since 1990, both in the production / manufacturing and the financial markets sectors there is a growing trend of mergers and acquisitions. The distribution of employees in corporations and limited companies as recorded by ICAP for 1994, (ICAP 1996), shows a significant shift in the number of corporations above 100 employees from 0.5% to 15.1% with 2.2% employing more than 500 people. At the macro level, the trends show that it is the old and well established firms which are leading the wave of mergers and acquisitions while, simultaneously, they are modernising, they are developing R&D activities and participating in R&D collaborations, and they are expanding using their own resources and not borrowed funds. But there are virtually no new large firms entries apart from the services, food and beverages and the telecommunications sectors.

One more negative effect is the dramatic decline of some of the highly vertical sectors of the manufacturing industry (such as machines and transport equipment or vehicles manufacturing and assembly) mainly due to a departure of large manufacturing multinationals from the Greek economy towards former Comecon countries. This trend is significant for Greece because:

1. It is the multinationals based in Greece which are usually the most vertically integrated and “intensive” materials and components user industries (i.e. Nissan,

Goodyear), thus their departure opens a "final - user" gap in the Greek industrial structure,

2. In a global business environment, the competitiveness of a country for large scale industrial investment is not only synonymous with cheap labour cost and geographic or natural resources-related advantages, but to the flexibility and skills of the labour force with respect to generic, critical and emerging technologies.

By combining the two trends, the overall size of Greek manufacturing as a percentage of the GDP is shrinking but the process benefits some sectors as it creates large, more stable entities which have the capacity to develop technology and business strategies and exploit economies of scale and other opportunities resulting from the single EU market. These efforts are supported by both Greek and EU funds[14].

7.4.: Identification of "critical" industries and selection of industrial sectors to be examined

The industrial sectors under examination are those involved in the production and consumption of mainly structural metals and ceramics (hence the title of the thesis) such as structural and consumer ceramics, cement, ferrous and non-ferrous metals and their products. These sectors are classified under the industrial groups of:

- *Non - metallic minerals*; among others the sector includes producers of cement, refractors, consumer ceramics and tiles, structural ceramics for structural and construction applications, glass and almost all other ceramic-based structural and functional materials (e.g. catalysts and ceramic coatings).
- *Basic metals;* the sector involves the production and first stages of formation and fabrication of ferrous and non-ferrous products such as aluminium, steel, iron, copper and chromium.
- *Metal products;* the sector includes the production of metal products or metal - based constructions for a wide range of applications but it does not include vertically integrated units such as shipyards. Two out of the three defence manufacturers are listed in this sector.
- *Electric and electronic materials and appliances;* the sector(s) involves the production of electric and electronic materials such as electrical cables and wires and other electrical and telecommunications materials and equipment.

[14] Within the Second Community Support Framework (CSF-II), the Operational Programme for Industry (OPPI) with a budget of 2.8 billion ECUs, concentrates on horizontal measures in order to improve the technological status of Greek industry and to provide support in issues of infrastructure, modernisation of companies, SMEs, and human capital.

- *Transport equipment & shipyards;* this sector is an intensive materials using sector and includes many high value added sub-sectors, such as shipbuilding, railway equipment, parts and machinery, repair and maintenance of aircraft and machinery and assembly of machinery and vehicles (like cars and trucks).
- *The construction industry*; the sector involves the construction of buildings, housing, and large scale infrastructure construction such as airports, underground railway systems, docks, roads, bridges and many others. The construction sector is a very intensive materials user (both structural and functional and in terms of both quantity and quality) but its role is largely neglected by both industrial and technology development schemes and sector studies.
- *The defence sector;* this sector includes three large manufacturing and assembly / maintenance units and many other supporting SMEs. The sector's statistics are spread within the metal products and transport equipment sectors. As with the construction sector, the defence sector is an intensive materials user within Greece.

These fields have a significant contribution to the issue of international competitiveness and the welfare of the Greek economy for the following reasons:

1. For their high potential with respect to the development and application of incremental and advanced materials (advanced metals and ceramics in particular),
2. Because they are complementary sectors,
3. For a number of strategic considerations, and,
4. For their current and future contribution to the competitiveness of the national economy.

More specifically, the selected sectors are important because of:

A) High material potential. If everything corporeal is made of something, the majority of everything is made of metals, ceramics and wood. The majority of the incremental, advanced and new materials are either metals or ceramics. In addition, these two categories of materials have the widest spectrum of applications both in terms of end-products and in terms of technological fields. As such, these materials classes have one of the biggest commercial impacts world-wide since they can be tailored to meet performance requirements of both specialised, bulk and every-day, commodity, applications.

B) The issue of complementarily. These sectors are complementary sectors and through materials technologies and producer - user relationships they can achieve high levels of industrial integration and formulate high-added value industrial sector/ clusters which, as identified in the previous section, is of strategic importance to Greece. These sectors form integrated materials producers - users systems/clusters because the output of some of them is necessary for the operational effectiveness and product quality of the others[15]. As such these sectors have complementary materials, technologies, services and business needs and roles. In addition, a significant part of the output of these sectors provides inputs to the food, beverages, textiles, chemicals, petroleum and refinery and especially the construction sector.

C) For a number of *additional considerations:*

i) The sectors chosen to be investigated as case studies by this thesis are dominated by a limited number of large firms which can respond to technological trends and have the capacity to take advantage of economies of scale[16]. In addition, as has been indicated in chapter 3 (section 3.6: materials and business opportunities) all the international examples of diversification and, in particular rejuvenation strategies based on materials technologies, involve structural materials industries diversifying into either advanced structural materials or into functional materials (with the exception of the textile industry). Greece has a much stronger industrial infrastructure in the production of structural rather than functional materials (apart from chemicals and refining / petroleum industries, the Greek *industrial activity* on production and large scale use of functional materials is very limited). As such, structural materials industries have more possibilities to develop functional materials units and enter new business areas rather than the opposite.

ii) The issue of output concentration: all the reviewed sectors are characterised by a very high concentration of the domestically produced output. That is, domestic production in each individual sector is dominated (concentration ratios[17] of more than 0.7-0.8) by a very small number of large, leading firms, while the numerous SMEs share less that 20% of the domestically produced output. Since the question is to map general industrial trends, mapping the developments within the predominant players of each sector (who have the ability to initiate and implement change) is a safe indication of the trends of the entire sector. The thesis sample contains many firms with market concentration figures exceeding 85-90% in their sectors (e.g. aluminium production, and cement).

[15] For example the ceramics sector is a materials supplier to the basic metals sector or the cement sector (refractors and high temperature materials for kilns and hazardous applications).

[16] Other sectors (e.g. the plastics sector) apart from a couple of multinationals are extremely fragmented and dominated by SMEs with no record of continuous R&D activities over the last seven years.

[17] The concentration rate equals with the annual output of producer Ci divided by the total output of all domestic producers.

Industrial Groups	Number of Companies	Total Assets	Fixed Assets	Depreciation	Dept	Net Worth	Gross Profit	Net Income	Personnel	Return (%)	Ration: Dept/Total Assets (%)	Net Income per Employee
Food Products	527	1036 992 438	636 552 532	238 011 947	652 457 029	384 535 409	363 402 222	63 960 947	45 292	16.63	63	1 412
Beverages	115	341 407 951	232 251 504	129 280 214	208 109 647	133 298 304	143 133 092	40 540 971	9 019	30.41	61	4 495
Tobacco Processing	25	102 306 889	33 076 211	14 963 713	79 086 950	23 219 939	27 654 573	5 544 681	6 373	23.88	77	870
Cigarettes	6	135 130 871	61 340 062	27 992 911	96 061 399	39 069 472	36 996 235	11 853 409	2 822	30.34	71	4 200
Textiles	369	537 005 683	385 223 349	181 338 228	272 147 385	264 858 298	108 754 702	25 715 519	30 580	9.71	51	841
Clothing-White Linen	337	184 722 730	81 627 020	29 814 967	115 176 065	69 546 665	49 901 706	6 122 352	16 062	8.8	62	381
Footwear – Leather Goods	77	38 927 108	16 128 472	8 455 825	24 633 008	14 294 100	11 743 109	1 336 410	3 310	9.56	63	413
Wood – Cork	62	111 494 977	77 123 616	30 516 342	67 447 222	44 047 755	21 986 927	2 524 135	3 819	5.73	60	661
Furniture	90	43 773 705	30 257 415	13 386 690	23 995 515	19 778 190	14 555 548	1 584 849	3 541	8.01	55	448
Paper – Paper Products	93	159 853 388	115 838 808	56 637 933	94 074 992	65 778 396	48 265 994	5 129 795	8 257	7.8	59	621
Newspapers – Magazines	59	77 241 098	36 054 888	13 315 792	54 342 536	22 896 562	37 097 826	2 350 626	5 879	10.27	70	400
Publishing and Printing	143	66 974 539	51 610 679	20 691 222	37 924 303	29 050 236	14 154 695	387 255	4 361	1.33	57	89
Leather –Fur	21	20 059 124	10 803 135	3 961 809	12 395 462	7 663 662	3 920 146	460 048	641	6.0	62	718
Rubber – Plastics	211	201 914 919	144 091 101	69 014 126	109 863 042	92 051 877	55 404 701	12 360 602	9 202	13.43	54	1 343
Chemicals	137	191 901 264	175 934 346	109 451 475	111 346 038	80 555 226	58 955 626	13 520 425	7 827	16.78	58	1 727
Pharmaceuticals – Cosmetics – Detergents	95	244 092 061	112 755 014	55 265 288	160 402 822	83 689 239	161 308 913	30 122 459	11 432	35.99	66	2 635
Gas Bottling	8	18 233 312	15 656 606	8 413 157	12 372 526	5 860 786	13 814 969	1 672 144	711	28.53	68	2 352
Petroleum - Coal	21	322 777 825	239 158 036	138 548 334	199 210 744	123 567 081	66 707 523	21 522 475	5 519	17.42	62	3 900
Non-Metallic Minerals	358	471 750 867	429 334 398	236 558 876	322 432 868	149 317 999	95 953 446	17 044 616	19 103	11.41	68	892
Basic Metals	32	356 726 099	430 295 465	265 056 011	208 017 345	148 708 754	43 347 064	12 594 800	8 390	8.47	58	1501
Metal Products	255	384 380 148	234 795 675	117 676 625	280 369 082	104 011 066	70 502 477	5 968 574	15 317	5.74	73	390
Machinery – Appliances	129	73 631 277	43 855 118	15 481 699	42 159 199	31 472 078	15 685 979	1997 542	3 538	6.35	57	565
Electric & Electronic Materials	102	236 882 179	120 963 031	54 707 872	147 682 060	89 200 119	67 117 668	17 137 564	6 930	19.21	62	2 473
Electric & Electronic Appliances	55	62 872 966	28 489 824	14 903 465	41 572 900	21 300 086	21 389 792	4050 586	2 768	19.02	66	1 463
Transportation Equipment & Shipyards	98	461 280 263	392 047 678	72 204 079	448 158 288	13 122 037	30 096 659	(23 181 900)	13 152	(176.66)	97	(1 763)
Miscellaneous Industrial Products	99	61 479 205	44 448 536	19 369 757	33 373 945	28 105 260	20 218 643	5 430 760	3 590	19.32	54	1 513
Total	3524	5943 812 906	4179 979 521	1945 018 357	3854 812 310	2089 000 596	1602 081 235	244 832 116	247 436	11.72	65	96 946

Table 7.1: Basic data of Greek Industry for the year 1994. (Source: ICAP 1996) – **Capital Figures in 000 Drs.**

D) Contribution to the competitiveness of the national economy

i) Overall contribution to the national economy: the contribution of these sectors to the national economy is significant because, as **Table 7.1** indicates, the basic materials producing sectors (non - metallic minerals and basic metals and electric and electronic materials) as well as their users (metal products, and transport equipment - shipyards) account for a significant part (X%) of Greek industry. According to **Table 7.2** these sectors account for 25% - 39% of the totals of the most important measurements of Greek industry.

Industrial Sectors	Total number of S.A. companies (%)	Total assets (%)	Fixed assets (%)	Personnel (%)
Non – metallic minerals	10.15	7.93	10.27	7.72
Basic Metals	0.9	6.0	10.29	3.4
Electronic & Electric Materials & Appliances	4.45	5.04	3.5	3.9
Metal products	7.2	6.46	5.6	6.2
Transport Equipment – Shipyards	2.7	7.76	9.38	5.3
Total	25.4	33.19	39.04	26.52

Table 7.2: Contribution of the structural materials related sectors to the total industrial basic figures. Source: Author based on Table 7.1

The figures of Tables 7.1 and 7.2, should be supplemented by the share of the ECU (X) millions turn-over of the **construction sector** since this is a major user of metals and ceramics. The construction sector accounts for 14.6% of the GDP (in 1994 values) and involves 350 S.A. and Ltd companies out of which 43 S.As are able to undertake projects of more than ECU 20.7 million[18]. Under the Second Community Support Framework (CSF-II), and for the 1994-1999 period, the construction sector (and its suppliers) will benefit by five (5) trillion Drachma or approximately 17.35 Billion ECUs channelled into large infrastructure public works (such as railways, underground, airports, new telecommunications, power plants) in order to modernise the national transport, energy and telecommunications infrastructure.

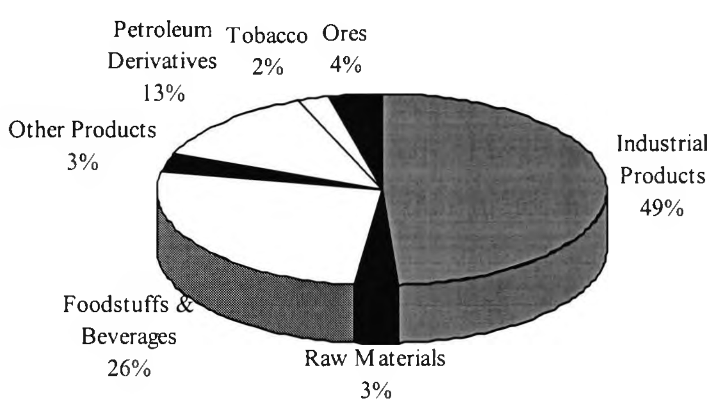
In total, 15000 large and small construction works are estimated to get the "go ahead" during the same period. Seventy-five (75) projects are expected to absorb 47,5% of the budget and thirteen (13) projects are expected to absorb 41.76% of the budget. The overall investment is expected to create 100,000 jobs and add 0.9% a year to

[18] Source: Association of Greek Contracting Companies (1994).

economic growth. GDP is projected to average an increase of 2.2% a year during the six-years programmes and it is expected to reach an increase of 3.5% by 1999 (Industrial Review 1996).

ii) Contribution to exports: in the first two decades after WWII Greek exports were largely agricultural and as late as 1955 the only industrial export was turpentine made from pine resin. The merchandise trade was partly offset by exports of invisibles such as earnings from tourism, shipping and remittances from immigrants but these sources are cyclical and subjected to exogenous factors. However, these intangible sources were primarily directed either to consumption or to the services sector and the civilian construction industry. Earnings from tourism and remittances displayed consistent annual growth during the 1960 to 1980 period but they have slowed down or stagnated during the 1980s. While the tourist industry still generates a small annual growth, the remittance balance today is negative[19] and most of the shipping earnings, if they enter the country, are primarily invested in the services sector with strong emphasis on banks, insurance, trade services and tourism.

Figure 7.1: Greek Exports During the 1993-1995 period.
Source: ETVA 1996



Today, the import / export ratio on tangibles is currently in the ratio of 4 to 1 and growing. Since entry into the EU, the contribution of industry to GDP has been in decline - 21.3% of GDP in 1980 to 13.9% in 1995 (NSS 1996). But since the late

[19] During the late 1950s and 1960s it was the Greeks who emigrated and sent remittances back to their families in Greece. Now, after a generation or more has passed, the majority of the overseas Greeks have either completely integrated with the local societies or they have returned to Greece as pensioners.

1980s manufacturing's contribution to exports has grown and, as **Figure 7.1** indicates, it has reached around 49% of all exports by value, although, there remains a strong bias towards agricultural or other raw materials, foodstuffs, beverages, tobacco, textiles and petroleum derivatives. However, the exports of the case-study sectors are characterised by a limited variety of products and a notable lack of differentiation and diversification in contrast to imports from both EU and other countries. When it comes to high-added-value industrial products the concentration of the domestically produced output is even higher (Chalikias 1995).

iii) The issue of commercial competitiveness. This issue involves the total trade balances (including revenue of both exports and sales in the domestic market) of the major industrial sectors. By observing the figures in **Table 7.3** - share of losses, **Table 7.4** (Industrial Production) and **Table 7.5** (Share of profits) it is possible to reach some firm conclusions.

Industrial sectors	1990	1991	1992	1993	1994
Metal products	45.5	35.6	62.5	17.6	13.4
Transportation Equipment & Shipyards	31.0	19.8	(P)	2.1	51.9
Basic metals	(P)	(P/B)	30.0	70.3	28.2
Non-metallic minerals	(B)	13.3	(P)	(P)	(P)
Textiles & Clothing	23.6	29.5	7.5	(P)	(P/B)
Electric/Electronic materials & Appliances	(P)	1.8	(P)	(P)	(P)
Wood products	(P)	(P/B)	(P/B)	10.0	5.6

Table 7.3: Shares (%) of losses of the most unprofitable industrial sectors during 1990 - 1994. Source: Greece in Figures, ICAP. (P/B) stands for Profitable or Balanced year.

Table 7.3 (losses) clearly indicates that the two sectors which are intensive materials users (metal products and transport equipment) are in constant deficit and losing badly over the last 5 years. The basic metals sector got into deficit in 1992 and is a major contributor to the total industrial losses ever since. This is because the sector faces severe competition through the globalisation of markets and import penetration by cheap products from East Europe and other origins (IOVE 1995; KEEM 1995). Textiles are losing badly but they made a small recovery (Table7.5 Profits) mainly due to mergers and acquisitions and improvements in cost reduction and operational effectiveness (SEV 1995; IOVE 1996). The non-metallic minerals sector (ceramics) is going through a restructuring period and retains marginally its profitability from 1992 onwards. In addition Table 7.4 (Industrial production) indicates that industrial production of these sectors fluctuates considerably and since 1990 they exhibit declining tendencies revealing that these sectors are losing ground to competition pressures.

	1985	1986	1987	1988	1989	1990	1991	1992	1993
Industrial production, total	107.2	106.9	105.5	110.8	112.8	110.1	108.9	108.0	104.8
Mining and quarrying	182.6	184.7	181.5	188.8	179.5	173.8	171.9	160.6	150.6
Manufacturing	101.0	100.3	98.3	103.2	105.6	102.6	101.7	100.6	97.2
Food, beverages and tobacco of which	121.5	113.6	107.2	117.0	126.6	119.9	127.1	135.0	134.2
Tobacco	119.3	110.3	94.7	99.8	92.2	112.3	113.7	108.5	107.7
Food	120.6	109.1	103.7	114.8	126.7	112.6	123.8	134.9	132.3
Other manufacturing of which	96.5	97.7	96.3	100.2	101.2	98.9	96.1	93.1	89.1
Textiles	95.5	102.0	104.0	101.3	99.1	95.4	86.7	79.3	74.1
Chemicals	121.6	115.7	116.3	125.8	132.4	133.3	126.8	122.6	127.2
Non-metallic minerals products	90.4	93.3	95.2	99.5	95.6	100.0	88.3	84.5	84.7
Basic metals	94.0	90.2	87.5	98.0	97.9	99.3	100.6	102.7	97.5
Metal products	89.7	96.3	82.0	90.5	83.8	74.4	73.6	74.8	68.5
Consumer goods industries	110.0	110.5	108.1	112.0	115.8	107.1	104.1	103.0	102.4
Durable	97.4	101.5	89.2	81.1	84.9	75.3	81.0	81.7	88.6
Other	111.4	111.6	110.1	115.3	119.1	110.4	107.7	105.8	103.9
Capital goods industries	81.2	79.3	76.3	83.7	82.9	92.1	92.1	92.1	84.4

Table 7.4: Industrial Production in Greece (1980 = 100). Source: OECD 1996.

Industrial sectors	1990	1991	1992	1993	1994
Non-metallic minerals	(B)	(L)	3.3	6.3	5.9
Basic metals	18.2	(P/B)	(L)	(L)	(L)
Electric / Electronic materials & Appliances	6.7	10.2	6.4	10.2	5.9
Transport Equipment & Shipyards	(L)	(L)	15.5	(L)	(L)
Food products	9.6	20.3	15.8	20.0	22.1
Beverages	6.7	9.7	12.4	12.4	14.0
Tobacco products	6.4	6.9	4.1	4.1	4.1
Petroleum & refinery products	7.6	11.2	8.3	7.7	7.4
Chemicals	8.0	7.9	4.9	5.2	4.7
Wood products	3.6	(B)	(B)	(L)	(L)
Textiles	(L)	(L)	(L)	7.1	(P/B)
Pharmaceuticals & Cosmetics	9.4	11.6	7.9	8.5	10.4
Other sectors	18.5	22.2	17.2	18.5	25.5

Table 7.5: Shares (%) of profits of the profitable industrial sectors during the 1990 - 1994 period. Source: Greece in Figures, ICAP. (L) stands for Losses and (B) for Balanced.

Moreover, a recent survey of Greek industry and Greek exports (Viomichaniki Epitheoricy 1996) revealed that almost 60% of the inputs of the profitable sectors (e.g. food, beverages, petroleum and chemicals) are not domestically produced. In addition, the author found during the interviews with construction experts (see chapter 9) that the construction sector is rapidly following this trend because many construction projects (like the Athens Underground) *impose materials performance requirements higher than the domestic output capabilities*. These facts place additional competitive pressure on the sectors reviewed.

However, the picture is familiar. The competitiveness findings of the Greek industrial sectors (which critical sectors are losing badly and which sectors do not) are almost identical with the findings of the US National Research Council 1989 study on "*Maintaining competitiveness in the age of materials*" for the US industry. This major study[20] indicated that out of seven selected industrial sectors, the basic metals, energy and transport / automotive sectors were losing badly with respect to international trade balances over the 1982-1987 period (see Tables 3.3,4,5) while the chemicals, aerospace and electronics were profitable. The NRC study underlined the finding / conclusion that the MSE domestic capabilities erosion or strength in both national and industrial level was one of the main reasons behind the deterioration or the growth of these industrial sectors. Industries with a high degree of materials R&D strategies integration into their technological and manufacturing infrastructure were doing well or retaining position, whereas others not following or adapting MSE strategies were losing competitive position. Could these considerations be reflected in the Greek case?

7.5: The national R&D and innovation system in Greece: status and organisation

This section presents the basic characteristics of the national system of science, technology, and more broadly, innovation, currently in operation in Greece, its structure and status. It is within these characteristics that materials technologies and policies are shaped and implemented.

7.5.1: Stages of the Greek innovation system

After W.W.II., the Greek system of science and technological innovation passed through three successive and distinctive stages:

- The first stage **(Stage I)** covers the period from the early 1950s up to the very early 1980s and is characterised by general, large scale, State subsidies used as

[20] See chapter 1, literature review and section 3.5.

industrial policy instruments rather than deliberate technology policy elements. The technology policy of the era put emphasis on basic research and it is characterised by the establishment of a limited number of basic research oriented national institutes during the 1950s and many new academic institutions and universities during the 1960s and 1970s.

- The second stage **(Stage II)** covers the period from the early 1980s up to the beginning of the 1990s (1993) and is characterised by a constant introduction of *major institutional changes* and new elements in the national science and technology infrastructure such as the establishment of new technology and research institutions, public - private R&D collaboration programmes and new R&D organisation, administration and evaluation schemes.
- The third stage **(Stage III)** covers the period from the end of 1993 up to 1999 and is characterised by the gradual integration of Stage II's changes, the introduction of specific technological priorities, the emphasis on competitive research and by the systematic introduction of technology transfer and technology diffusion mechanisms.

During the **first stage** science and technology were two areas which were traditionally disregarded in Greek initiatives, both in public and private arenas (Giannitsis 1984, Vaitsos and Giannitsis 1987, Korres 1995). On the contrary, the Greek industrial policy was characterised by the establishment and growth of many (pre-selected) materials related sectors (e.g. basic metals such as aluminium and ferrous metals industries, heavy transport equipment and shipbuilding). These choices, however, were not supported by relevant national technology policies. From the late 1950s to the late 1970s some effort was devoted to basic scientific research in a limited number of public agencies (Ministry of Agriculture), a limited number of basic research oriented national research institutes (e.g. the National Centre for Scientific Research "Democritos" established during the late 1950s) or in universities under the auspice of the Ministry of Education and Culture. Industrial research was extremely sparse, dominated by technology transfers (royalties) and isolated to a very small number of companies which were either under the influence of the Greek public sector or branches of multinationals. Early science and technology efforts were hindered by a lack of priorities, consistency, reliable institutional and structural infrastructure and insufficient resources (the Gross Domestic Expenditure on R&D was the lowest in EU - see Annex 7.1). In addition, resources for R&D were dispersed on too many objectives creating contradictions, multiplication of efforts and poor results (Deniozos 1993, Planet 1994, Korres 1995).

As a point of reference, the **second stage** didn't begin until the early 1980s when conscious effort was made to improve R&D statistical data, to enhance industrial research and to complement scientific efforts with application oriented initiatives.

Budget appropriations for R&D expenditures (GERD) increased appreciably throughout the 1980s from 0.16% of GDP to 0.46% in 1994 but the participation of industry and services as a percentage of GERD remains disproportionately low (around 25%) while the respective rate for developed countries is 50% and in some cases 75-80% of the total (e.g. South Korea). Given that GERD has a substantial effect on the economic and social development of a country if it exceeds 1% of GDP (OECD 1996), it is the ultimate goal of the Greek GERD to reach the Community's average of 2% of GDP in a time span of 15-20 years from 1992 onwards. During the last 10 years considerable progress has been achieved (the national R&D programmes have managed to increase the industrial and services sectors participation for short to medium term projects) but even official sources (Ministry of Development 1998) recognise that there is still a long way to go in achieving the desirable levels of R&D expenditures. For presentation reasons, a more thorough overview of the figures of the research and technology developments in Greece (data and indicators) is provided by **Annex 7.1** .

During the same period (1981 - 1993) there has been a continuous introduction of new elements in the Greek national Science and Technology institutional and infrastructure system with the most outstanding being the establishment of the Ministry for Research and Technology (1982), and then, the unification[21] (1985) of the Ministry of Research and Technology with the Ministry of Industry, Energy and Natural Resources to form the *General Secretariat for Research and Technology (GSRT)*[22] and the Ministry of Industry, Energy and Technology, currently Ministry of Development[23]. In addition, a number of major institutional changes were introduced with the aim to strengthen the Greek innovation system. These institutional changes are listed in **Box 7.1** while a summary of the most important of them[24] is provided by

[21] According to the 1514/85 law on the "Development of Scientific and Technological Research" and the unification law of 1558/85.

[22] GSRT is no more than 21 years old. Its predecessor, the Authority for Scientific Research and Technology (ASRT), was founded by law 706/77 as a department of the then Ministry of Co-ordination. In 1982, through law 1266/82, ASRT formed the nucleus of a new, independent Ministry for Research and Technology. Finally, in 1985, the law 1558/85 combined that Ministry with the one for Industry, Energy and Natural Resources to form the current GSRT which today is one of the Secretariats of the Ministry of Development.

[23] The Ministry of Development encompasses the Ministry of Industry, Energy and Technology and the Ministries of Trade and Tourism.

[24] Such as the establishment of the national Organisation for Industrial Property, measures for financing technological innovation, the structure and the aims of the National Advisory Council for Research, the Government Committee for Co-ordination of Research and Technology Modernisation and the University Liaison Offices.

Annex 7.2 based on information obtained from GSRT publications and documentation.

1. The introduction of project and programmes funding procedures, peer evaluation, monitoring of projects and elements of research planning.
2. Creation of new research centres mainly outside Athens, in new scientific sectors and redefinition of the operational framework of the existing research centres.
3. Creation of six sector technological institutions (S.A.) for industrial research and technological services aiming to transfer the diffusion of technology throughout the productive web, especially the traditional industrial sectors. These companies service *the metals, ceramics,* shoe and leather, marine, textiles and food technology sectors.
4. Improvement of the status of researchers (payment and benefits).
5. Restructuring of universities and technical colleges and establishment of the University Liaison Offices (via the 1268/82 law and the Higher Education Act of 2083/1992).
6. Development of a network of innovation offices for the diffusion of information.
7. Creation of data banks and information networks for the exchange of information between the national and private research centres and the universities.
8. Creation of the National Documentation Centre (NDC).
9. Creation of an independent patent office (the Organisation of Industrial Property) with strong competence in dissemination of information with the law 1733/87.
10. Creation of the National Institute of Agricultural Research (law 1845/89 for development and application of agricultural research).
11. The institutionalisation of measures for the financing of technological innovation.
12. The creation of a National Advisory Council for Research (NACR) (1988).
13. The creation in 1992 of the Government Committee for Research and Technology Modernisation (KYSETE).
14. The launching of a number of national R&D schemes (see below) aiming primarily to support industrial research, human resources and the national R&D infrastructure.
15. The launching (1993-1994) of eleven sectional technology foresight studies reviewed in chapter 8.

Box 7.1: Institutional changes introduced in the Greek national innovation system during 1988-93.

The **third stage** of the Greek technology policy commences in 1994 with the design and launching of the second "*Operational Programme for Research and Technology*" **(EPET II)** and the restructuring of the national R&D programmes on the basis of performance evaluation outputs. EPET II is a significant stage in Greek technology policy because it attempts to enforce a complementary action of both horizontal and vertical technology policy elements with a longer term view (duration of EPET II: 1994-1999). It introduces for the first time specific technological priorities and provides emphasis on information diffusion mechanisms. EPET II is a huge "umbrella" operational programme which currently encompasses almost all the elements of the Greek innovation system. It is analysed in extensive detail in following sections and with respect to materials technologies in chapter 8.

7.5.2: Administrative structure and the role of the General Secretariat of Research & Technology (GSRT)

This section addresses the issue of which agency defines the tasks, targets and priorities of the national technology policy and which agency designs and directs the national technology policy in Greece.

According to statute of law 1514/85 on the "Development of Scientific and Technological Research", the "*General Secretariat of Research & Technology*" (**GSRT**), as an integral division of the Ministry of Development, spearheads the Greek effort towards the scientific and technological development and synchronisation of the Greek economy with the pace and procedures of European integration (GSRT 1996). GSRT is responsible for the following activities:

- charting and carrying out national policy in the fields of research and technology through the design and implementation of relevant programmes;
- activation and creation of research and technology infrastructure;
- technological development setting out research and technological directions;
- investigation of the consequences of research and technology on the economic, social and cultural development of the country.

In addition, since 1992 the GSRT:

- funds scientific and technological activities in sectors of high economic potential.
- plans and funds specific activities for technology transfer.
- plans, creates and develops the country's research and technology web through the technological and research centres.
- develops international collaborations and bi-national agreements.
- promotes, assists and co-ordinates the participation and integration of Greek R&D teams and organisations in programmes of the EU and other international organisations and initiatives.
- plans and carries out actions towards propagation of the technological culture.

In order to respond effectively to its missions GSRT is organised in six sub-divisions and directorates. The organisational structure of GSRT is summarised in **Figure 7.2**.

Moreover, GSRT has the main responsibility for the design and application of the national R&D programmes. In addition, GSRT supervises and supports twelve research organisations, nine technological organisations, the Greek Atomic Energy Commission and the National Documentation Centre, and four technological parks.

Organisational Structure of the General Secretariat of Research and Technology

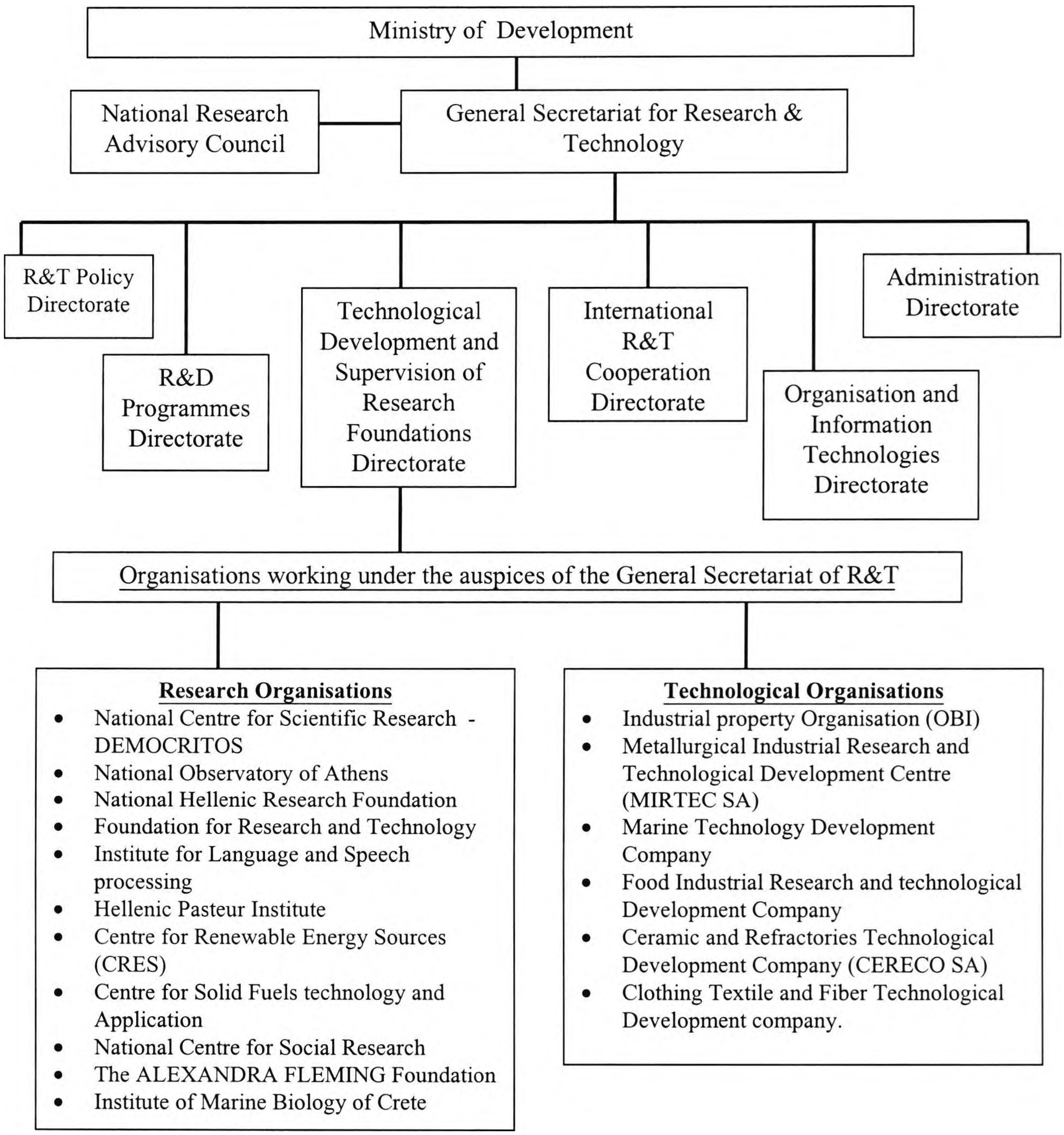


Figure 7.2: The organisational structure of GSRT. Source GSRT 1996.

On its own initiative GSRT has created six industrial research and technological development companies[25] (right column of Figure 7.2) which offer research and technological services and address specific technology and production problems of SMEs. Furthermore, four technology parks have been created with the aim of providing to pioneering industrial units high-grade facilities in close proximity to

[25] Two of these companies are dedicated to metals and ceramic technologies.

research establishments, services and know-how, so that they will be in the position to exploit commercially the results of scientific research.

According to the above, GSRT (and the Ministry of Development) *is the primary* public agency for the formation and implementation of science and technology policies in Greece. However, until 1996, GSRT had not achieved the desired levels of co-ordination on the design and execution of the national science and technology policy, mainly because many other public agencies and institutions (such as the Ministries of Defence, Agriculture, Health, Transport and notably the Ministry of Education and Culture) have the authority and capability to design and finance their own research programmes according to their own discretion and with agendas subjected to the specific nature of their field. As PS1 put it, "*GSRT tries to provide some directions, especially thought the R&D programmes but the other Ministries do not harmonise their efforts*".

The strongest influence comes from the Ministry of Education and Culture[26]. Apart from the influence on the public R&D budget allocation (see Figure 4 in Annex 7.1), the Ministry of Education and Culture has under its direct (and until 1992, very tight) control the entire Greek academic system where most of the basic research and the applied pre -competitive research takes place. The Ministry of Education and Culture, nevertheless, exercises its control on the Greek academic system by budget allocation which does not take into account a specific portfolio of technological or scientific priorities and by "loosely" supervising (through budget allocation) the undergraduate (and after 1995 postgraduate) curricula of each school or department. As such each university-based research group or laboratory has considerable freedom to concentrate on research areas of their choice and then seek financial support.

In addition, the research institutions supervised by the GSRT enjoy considerable decision making autonomy and, apart from governmental subsidies, they have the ability to raise funding for R&D by both domestic and international sources. Until 1996, GSRT did not have the legal authority or the institutional means to enforce specific, mission or application tailored priorities. Supervision was carried out through auditing and quotas of budget allocation (public subsidies) based on criteria of performance excellence. However, each research institution, within the boundaries of its mission framework, is allowed to select its own R&D activities but contrary to

[26] The influence of the Ministry of Education and Culture is substantial because it controls the allocation of almost 50% (in 1991) of the State funds for R&D (channelled mainly to the academia) and supervises the State Universities, the higher education technological institutes and some research institutions in Greece. It should be noted that the Higher Education Act of 2083/92 strengthened the influence of the Ministry of Education and Culture as it institutionalised its ability to design, finance, allocate and supervise research projects and R&D portfolios.

the, say, Japanese research institutions acting under the auspice of MITI, they are not in position to sustain large scale R&D *portfolios* individually.

Until 1992 there was no institution or agency responsible for the co-ordination of the R&D activities of all the different Ministries and public agencies. The establishment of the National Advisory Council for Research and the Government Committee for Research and Technology Modernisation aimed to close this co-ordination and planning gap but they have just started to make an impact from 1994 onwards which has been materialised with the introduction of vertical measures and fields selection in sub-programmes of EPET II. Nevertheless, apart from the role of the Ministry of Education and Culture and the Ministry of Agriculture, the contribution of many of these Ministries to the governmental expenditure for R&D is rather limited (see Figure 4 in Annex 7.1) while the importance of GRST for the design of R&D programmes and the allocation of R&D funds remains strong (see Figure 5 in Annex 7.1).

7.5.3: Fundamental priorities of the Greek national technology policies

During the last 15 years the Greek technology policy priorities have passed through three consecutive and distinctive stages.

The first step (1984-1989) aimed to make a first impact on the national R&D system in order to encourage both public and private R&D activities and obtain "market feedback" for potential priorities and existing weaknesses. The second step (1989-1993) continued the established activities and in parallel it aimed to create a strong national R&D infrastructure. The third step (1994-1999) builds upon the previous steps, enriches the national R&D infrastructure with new elements (e.g. technology transfer mechanisms) and gradually puts emphasis on the definition of specific technological priorities in order to enhance the competitiveness of the Greek industry and economy. In more detail:

Since 1984 and up to 1989 the fundamental priorities of the Greek national science and technology policy were (in order of importance):

1. Expand the country's scientific and technological capacity, particularly in advancing technologies including elements of R&D infrastructure, human resources, innovation diffusion networks and mechanisms;
2. Enhance industrial research and improve co-operation between the scientific community and the productive system (emphasis was put on the creation of linking mechanisms between research oriented institutions and industry) and,

3. Encourage technology transfer (introduction of new, generic technologies in the Greek research and production systems) and technological innovation.

The same policy objectives **but in reverse order of importance,** were pursued in the second period (1989-1993) in conjunction with the application of two major structural programmes targeting the reinforcement of the national R&D infrastructure and financed jointly by the Greek State and the EU: the Science and Technology for Regional Innovation and Development (STRIDE) and the first National Research and Technology Programme (EPET I - see below).

The next technology policy step came in 1994 with the launching of the second *Operational Programme for Research and Technology* (**EPET II**). Since 1994, and while the technology policy priorities of the 1990-1994 period **remain strong,** the priorities of developing technological fields of particular economic importance and technology diffusion mechanisms were added.

7.5.4: Implementation of the national technology priorities

The major (and almost exclusive) instrument in the hands of GSRT for the execution and implementation of the national science and technology priorities is the design and application (implementation) of a set of structural or collaborative R&D programmes with complementary targets.

During the 1989-1993 period the objective of supporting the national R&D infrastructure was pursued by the application of two major structural programmes financed jointly by the Greek State and the EU: the Science and Technology for Regional Innovation and Development *(STRIDE)* and the first Community Support Framework (CSF - I) programme which took the form of the first National Research and Technology Programme *(EPET I)*. The activities of both STRIDE and EPET I were designed primarily to improve the national innovation system's shortcomings, physical weaknesses and deficiencies and for the 1989-1993 period, they were the main instruments of supporting science and technology infrastructure in Greece. EPET I gave considerable attention to materials technologies through its sub-programme 1, action 1 and 4 by the establishment of three materials related technological institutions[27] and considerable support to materials related laboratory equipment while STRIDE was more basic research oriented and supported only

[27] MIRTEC S.A. (Metals), CERECO S.A. (Ceramics) and the materials related CLOTEFI S.A. (Textiles and fibers).

chemistry related materials technologies. The main objectives and structure of EPET I and STRIDE are summarised in **Annex 7.3**.

All the other horizontal technology policy priorities were pursed by the design and the application of a set of national R&D collaborative programmes which targeted the support of industrial research, human resources and the creation of links between the research and industrial institutions of the country.

In more detail, the first set of national R&D programmes was launched during the 1985-1989 period with the launching of three *complementary but horizontal in character* programmes. They were the:

- Programme for the Enhancement of Research Manpower (PENED) exclusively dedicated to higher education and training *(human resources)* ,
- Co - Financing Programmes (SYN) with the aim to establish *direct co-operation (links)* between research institutions and the country's social and productive establishments in order to solve problems and satisfy needs they confront.
- Programme for the Development of Industrial Research (PAVE)[28] with the primary objective to promote *industrial research* and support technological innovation in industry,

The budget of these programmes was not allocated in projects subjected to quotas based on specific field priorities. Materials technologies (or any other technologies) were not identified as priority fields.

The next step came in 1994 with the launching of the second Community Support Framework (CSF- II) for Greece and the second Operational Programme for Research and Technology (*EPET II*). EPET II is a huge "umbrella" style programme which has incorporated the existing national R&D programmes (PAVE, SYN, PENED) and has created many new R&D schemes targeting specific technological fields, technology services, regional support and development, technology transfer and diffusion mechanisms. For presentation reasons, **Annex 7.5** provides a brief presentation of the most important R&D schemes and sub-programmes of EPET II including information on the aims, requirements and implementation of each activity.

EPET II had an initial budget (1994) of 579.068 million ECUs and has 5 sub-programmes divided into measures and actions. The implementation of the programmes takes place gradually during the period 1994-1999. Funding is provided by a combination of Greek, EU, and private sources on the basis of quotas subjected to the individual needs of each sub-programme and action.

[28] PAVE is by far the most important of the three. It is 5 times larger (in terms of scale and budget allowance) than both SYN and PENED combined.

Table 7.6 provides the budget allocation of EPET II as adopted by GSRT and presented according to sub-programmes and measures. **Annex 7.4** presents an executive summary of the main policy guidelines, directions and priority areas of CSF - II and EPET II.

	In billion Dollars		In million ECUs	
	PUBLIC	TOTAL	PUBLIC	TOTAL
	122,35	168,93	421,879	579,068
SUBPROG.1: R&D IN SELECTION FIELDS	35,99	43.63	124,113	150,441
1.1 ENVIRONMENT AND QUALITY OF LIFE	7,20	8,73	24,823	30,088
1.2 LIFE SCIENCES	6,17	7,48	21,277	25,790
1.3 INFORMATION TECHNOLOGIES	10,28	12,47	35,461	42,983
1.4 NEW MATERIALS	10,28	12.47	35,461	42,983
SUBPROG.2: .INDUSTRIAL RESEARCH, TECHONOLOGY TRASFER AND INNOVATION	43,85	77,92	151,223	265,245
2.1 INDUSTRIAL RESEARCH (PAVE A, PAVE B)	13,79	27,58	47,553	95,106
2.2 APPLIED RESEACH (YPER, SYN)	3,50	5,44	12,056	16,548
2.3 TECHNOLOGY TRANSFER	22,45	39,74	77,429	137,042
2.4 NET WORKS, DATABASES, NAT.DOCUMENTATION SY	2,06	2,42	7,092	7,092
2.5 INTERNATIONAL R + D COOPERATIONS	2,06	2,74	7,092	9,456
SUBPROG.3: SUPPORT/EXTENSION OF R+D STRUCTURES	26,74	29,57	92,199	101,950
3.1 SUPPORT TO PRIORITY AREAS	11,31	14,14	39,007	48,759
3.2 EXTENSION IN THE NORTHERN AXIS	10,28	10,28	35,461	35,461
3.3 EXTENSION IN THE SOURTHERN AXIS	5,14	5,14	17,730	17,730
SUBPROG.4:IMPROVING OF HUMAN CAPITAL				
	11,65	13,70	40,160	47,247
4.1 TRAINING OF R+ D PERSONNEL (PENED)	8,56	10,07	29,522	34,732
4.2 MOBILITY, LINKS WITH PRODUCTION	3,09	3,63	10,638	12,516
SUPBPROG.5:MANAGEMENT OF CSF	4,11	4,11	14,184	14,184
51 ADMINISTRATION-FOLLOW UP	2,06	2,06	7,092	7,092
5.2 AWARENESS-EVALUATION-SUPPORTING STUDIES	2,06	2,06	7,092	7,092

Table 7.6: Community Support Framework For R&D (EPET II): Financing Table. (Public expenditure does not include 6 billion ECUs to be given on a regional level. (1 ECU = 290 Drs) Source: GSRT 1994.

Action	Are materials activities included?	Are materials activities targeted as priority areas?	Are specific materials or their application fields targeted?
Sub-programme 1: R&D in Selected Fields			
EKVAN	Yes	Yes	Yes
EKVAN-P: Special Action for Northern Greece	Yes	Yes	Yes
Sub-programme 2: Industrial research, Technology Transfer and Innovation			
PAVE	Yes	Yes[29]	No
YPER	Yes	No	No
SYN	Yes	No	No
Research & Technology Parks	Indirectly Yes	No	No
Technological Institutions[30]	Yes	Yes	Yes
Technomathia	Very limited	No	No
Open Gates	Very limited	No	No
PEPER	Very Limited	No	No
Technology Brokers	Yes	No	No
PAFOS	Yes	No	No
Bi-lateral International R&D collaborations	Subjected to the terms of the agreement	Subjected to the terms of the agreement	Subjected to the terms of the agreement
Technology Performance Financing	Yes	No	No
Sub-programme 3: Support and Extension of R&D Infrastructure			
Support of R&D Infrastructure	Yes	No	No
Documentation libraries and library networks	Indirectly Yes[31]	No	No
LAERTIS	Mega – Science project in theoretical and applied physics		
Sub-programme 4: Human Capital and Human Resources			
PENED	Yes	Yes	Yes
Human Science and Technology Networks	Yes	No	No
Diavlos	No	No	No
Sub-programme 5: Management / Administration of the Second Community Support Framework			
Funding of Scientific Conferences	Yes	Yes	No
Information Technology related initiatives	No[32]	No	
Other administration and evaluation measurements	Indirectly Yes[33]	No	No
Other International R&D Collaborations			
BRITE / EURAM	Yes	Yes	No

Table 7.7: Operational Programme for Research and Technology (EPET II), after two years of application (1994-1996), and materials activities. Source: Author based on GSRT data .

[29] Since 1994.
[30] Support of the existing ones or establishment of new ones.
[31] Materials are included; however, there is no prediction for libraries or data bases dedicated to materials.
[32] Do not confuse with modelling and simulation activities.
[33] Evaluation of materials programmes is included.

Given that during the 1989-1993 period the national R&D infrastructure and national R&D capabilities have been dramatically improved, EPET II attempts to focus the national R&D efforts on specific, pre-selected technological fields of high economic interest. For the first time the concept of emerging technologies, of generic and enabling technologies (including new or improved materials and S&P methods) and the concept of identifying technological fields of critical economic importance are introduced.

Simultaneously, a complementary set of horizontal activities aims to complete the necessary institutional changes and to optimise the effectiveness of the national innovation system by putting emphasis on *links* and technology diffusion mechanisms.

The **connection** of sub-programmes and actions of EPET II **with materials technologies**, (if any), is identified with **Table 7.7** but it is fully analysed and discussed in chapter 8. As seen from Table 7.7, only EPET II's sub-programme 1, *EKVAN* - The Programme of Research Consortia for Improving Industrial Competitiveness, and PENED possess three (Yes) indications through all columns of Table 7.6. EKVAN is the first national R&D programme which clearly pre-selects technological priorities and aims to strengthen industrial competitiveness *by strengthening R&D activities in high economic potential sectors*. The programme supports five pre-selected fields (see Table 7.6) including pre-selected materials and S&P technologies. EKVAN receives detailed analysis in chapter 8.

In addition, PENED identifies five research sectors one of which is dedicated to emerging technologies including biotechnology, *new materials and composite materials*, information technologies and transport technologies. On the contrary, PAVE does not identify technological priorities. Since 1994 however, it has given priority (in general) to proposals for projects related to S&P technologies.

7.5.5: Implementation of the national R&D collaborative programmes

The priorities of all major national R&D programmes retain a horizontal approach (apart from EKVAN) in order to be aligned with the clearly horizontal national technology policy priorities described above and the institutional changes described in section 7.5.2. Moreover, the implementation of all national R&D programmes (including EKVAN) is identical and has a strong "bottom-up" approach.

After the announcement of the aims of the programme, calls for proposals and submission of project proposals is made. After evaluation, funds are allocated to successful proposals. Since there is **no** pre-selection or pre-determination of budget threshold on the basis of specific technologies or fields of application, all business, manufacturing and services sectors, and all types of research organisations compete on equal terms. The evaluation/selection criteria[34] (see **Annex 7.4**) concern the quality and reliability of the proposal and its relevance with the general targets of the programme. There are no special arrangements to take into account the technological nature and the special technological requirements of different sectors or technology groups. When a project is approved, budget is gradually released until the completion of the project. The duration of funding varies between 2-3 years apart from some exceptional cases (national infrastructure projects and EKVAN projects) where it is extended to 4 years. When companies participate as the final project results as users, they contribute to the projects budget (up to 70%) in return for exclusivity of the research rights (patents and other results).

7.5.6: National infrastructure issues

Laboratories and R&D infrastructure. The Greek scientific infrastructure is field dispersed and it is primarily dominated by academic and other public research institutions. In 1994 figures (GSRT 1994), in total, there are 445 laboratories (240 university, 101 technological education and 104 research institutions and other agencies laboratories) able to undertake research or R&D activities.

In more detail, apart from the academic institutions, most of the Greek research infrastructure operates under the auspices and supervision of GSRT. GSRT supervises 13 large research institutions, six (6) technological institutions and two (2) university-based research institutions able to support medium to large scale R&D activities (see **Figure 7.2**). Additionally, the Ministry of Education and Culture supervises 17 universities and 11 technological institutions (TEI). Nine universities and nine technological institutes have laboratories able to sustain R&D activities on science and engineering principles. Finally, there are 23 laboratories allocated in various public sector organisations such as the Ministry of Agriculture, Ministry of Finance, Ministry of Health and Ministry of Transport.

National Research Institutions. According to the opinion of PS1 and PS4 (1996), there are two kinds of such institutions: those established during the early 1950s or

[34] Like technological feasibility of the proposal, originality of the proposal with respect to the *Greek* technological reality, technological and commercial importance of the proposal / project and credibility (in financial terms) of the proposal. A more detailed sample of the selection criteria is provided with Annex 7.4.

before W.W.II. (like Democritus and the National Observatory) and those established during the 1980s (such as the Centre of Renewable Energy Sources, the six technological institutions). The rationale behind the establishment of the first generation of research institutions was the progress of science, the "science-push" attitude and the linear model of innovation. Excellence in science was expected to generate technological and commercial advantage. During this period the largest research institutions were established and indeed their mission was scientific excellence and national security. With respect to materials, today, these institutes are pockets of excellence in basic research focused on principles of theoretical physics, and functional materials for electromagnetic applications.

The rationale behind the establishment of the second generation of research institutions was the concept of "mission oriented" research. The aim is to maximise scientific output in pre-selected areas of great economic interest. Typical examples are the Centre for Renewable Energy Sources, the Centre for Solid Fuel Technology and Applications and the two university related research institutes, both of them dedicated to chemical engineering and processes. The two university related research institutes were created as academic research "spin-offs" with the aim to further enhance and commercially exploit exceptionally good research results in the areas of materials processing and chemical engineering. The next stage is the gradual integration of these research institutions into the functioning of the recently established technological parks.

The 23 laboratories operating under the auspice of various public agencies (apart from GSRT) have limited capabilities and their mission is mainly reserved for testing and monitoring activities (like the General Chemistry Laboratory of the State). On the other hand, the large number of academic laboratories are organised on the basis of small, flexible, research teams (five to twenty people) with considerable scientific, but limited research scale, capabilities.

In view of the above, Greece does not have national laboratories like the large federal laboratories of the USA, Germany or Switzerland capable of carrying large scale R&D activities[35]. In addition, while there is a considerable increase in the total number of enterprises with R&D activities (see below) in the public sector there is a relative stagnation in the formation of new centres since 1993 (there has not been establishment of new research or technology development centres or sector

[35] The National Centre for Scientific Research DEMOCRITOS is the largest research institution in Greece with a man power of 700 researchers and administration personnel (in 1994 figures). However, the institute is organised on the basis of many separate divisions, sub-institutes and research teams each dedicated to a different field. The National Research Foundation is the second largest research institute with a manpower of 420 researchers and administration personnel and similar structure.

specialised agencies). With respect to the support of materials technologies, some serious infrastructure gaps have been identified and they are discussed in chapter 8.

The private sector contribution to the overall R&D effort shows a high concentration in a limited number of large firms. According to GSRT sources - see **Table 7.8**, in 1993 there were approximately 250 companies (in 1986 there were only 144) with a record of R&D activities; only 21 enterprises spend more than 350,000 ECU annually in R&D activities.

GSRT Classification	Number of Companies	Annual R&D Budget (in thousand ECUs)
Exceptionally important R&D activities	21	More than 350
Important R&D activities	66	Between 70 and 350
Limited R&D activities	163	Between 3.5 and 70

Table 7.8: Classification of private companies according to the annual average R&D expenditure. Source: GSRT 1993.

However, Karageorgiou (1996) argues that the private sector figures on R&D activities are inaccurate - the real figures are much higher. Enterprises, Karageorgiou says, deliberately underestimate their R&D capabilities and the figures of their R&D activities for a variety of reasons, most importantly taxation and governmental subsidies reasons[36]. As such, the official figures are underestimated. To get an idea of the real picture, Karageorgiou continues, we should look upon the figures of the applications for R&D projects within the frame of the various national (and occasionally international) R&D collaborative schemes. The projects of EPET I required a 30% minimum industrial funding contribution by the participating companies while this figure rose to 40% minimum with EPET II.

For each programme of EPET II, the approved projects are just a fraction of the submitted proposals which reveals that many more enterprises are prepared to invest in R&D activities for at least 3-4 years (e.g. EKVAN) and have (or are prepared to develop) R&D capabilities.

Education and Human resources

In Greece there exist 17 universities with approximately 6000 faculty members (1994 figures). The duration of studies for bachelor degrees is 5 years for engineering principles and architecture, 6 years - for medical principles and 4 years for all other

[36] If a company proves that it has a reached a threshold point in R&D activities then it is not liable any longer for an array of governmental subsidies for R&D.

principles. There are also 11 technological institutions of higher learning (TEI) geographically distributed around the country. Until 1992 the only postgraduate programmes available were research programmes leading to the PhD award. The Higher Education Act (see Annex 7.2) gave the opportunity to Universities to design and develop postgraduate studies on the basis of taught courses and short - term research with a duration of 1-2 years and leading to the equivalent of M.Sc. or MPhil degrees.

The special role of universities and research institutions in the Greek system of innovation

As identified in section 7.5.4, the implementation of the national science and technology priorities passes through the design and implementation of a set of national collaborative R&D programmes. As can be seen from Annex 7.3, almost all of the national R&D collaborative programmes necessitate the formation of collaborations between research organisations (universities, technological and research institutions) and manufacturing or services enterprises or other agencies. Hence, both academic and research institutions hold a central role in the implementation of the national science/technology strategies. Further, research organisations (university departments in particular) hold a crucial role for scientific/technological progress in the Greek national system of innovation for a number of additional reasons:

- The profile of the modern Greek academic: The image of the "pure" basic research- oriented academic is rapidly fading away. Since the middle 1970s, the profile of the members of academia and R&D community increasingly involves people with combined academic and industrial experience, with significant international experience (academic and industrial), and with very strong personal contacts in both the domestic and international academic community.
- The influence of the R&D community in the technology planning system of Greece: Due to the early shortcomings of the Greek innovation system[37], members of academia with international experience were frequently better informed about international developments in science and technology than the majority of Greek industry. Especially in many emerging technologies, it is the Greek universities and research institutions which maintained links with international developments. As such, during the early stages of the design of the national R&D programmes and the

[37] Such as the pre-1990s lack of interest of the Greek industry for the value of R&D activities.

national technology priorities, their extensive participation on GSRT and other technology policy committees was justified[38].

- Accumulated expertise and R&D collaborations: Many members of the Greek research community have considerable experience from participation in national and international R&D programmes which have provided them with additional depth of knowledge and applied research experience. Therefore, many academic laboratories, due to the accumulated experience in their fields, can act as focal points for the diffusion and transfer of knowledge into Greek industry. In fact, in many collaborative projects, it is university departments and research institutions that technologically "pull" industry and not vice versa. Given that the majority of Greek companies do not have specialised R&D departments responsible for technological development and planning (see Table 7.8), the connection with university departments and research institutions becomes crucial not just for technological reasons *per se* but for the ability of a given firm (or even entire sector) to be aware of international developments and to be able to participate successfully in the national R&D collaborative programmes.

<u>Institutional changes in Higher Education.</u>

After a new organisational framework for universities was established in 1982 (law 1268/1982) research activities undertaken in the universities have expanded considerably and after a major restructuring (according to the provisions of the Higher Education Act of 2083/1992) they became the major source of income for many departments or divisions and laboratories[39]. The Higher Education Act gave the freedom to academic departments and divisions to design their own strategy and it provided the legal framework for both academic and research institution laboratories to market their research and scientific capabilities seeking "customers" in both domestic and international markets. These "marketing" activities were further enhanced by the establishment of Liaison Offices with the aim to promote university - industry collaborations and the tangible implementation of R&D results and know-how capabilities.

Finally there are the issues of the connection of academia to the domestic industrial needs and the use of education as a national development instrument, the issue of scholarships on emerging technologies and the issue of continuous education. These

[38] As experts PAC3 and PAC1 identified, GSRT usually takes very seriously the opinions of academics and, in general, academics have high participation in the national programmes planning and evaluation committees.

[39] Since 1982, participation in EU research initiatives (i.e. the BRITE / EURAME programmes) has risen steeply and it became the primary axis of development and source of income for many academic divisions in engineering or science departments. After 1992, research for domestic needs started to balance the research portfolios of academia.

issues are reviewed with respect to their connection to materials technologies in chapters 8 and 9.

Technological information diffusion mechanisms. For several years this task was carried out by the operation of innovation offices in various Greek cities supervised by the Organisation for Small and Medium Size Enterprises (EOMMEX). An engineer with special training assists small local companies to bring their own new products and ideas into the market. The project has not expanded at the planned pace. Instead, two innovation centres have been created by EOMMEX one of which is very active in training people and advising small entrepreneurs in the field of information technology (software development and software services in particular). Other activities in the direction of information diffusion include the creation of the National Documentation Centre, the establishment of the PRAXIS group (subsidised by the EU operating under the auspice of SEV), computerised data bases and information networks and the technology transfer and diffusion activities of EPET II (see Annex 7.4 and 7.5). There is no MSE predisposition or specialisation in any of these efforts.

Finally, the issue of standards and the institutional framework for the finance of innovation is reserved for discussion in chapter 8. The issue of international R&D collaborations and the participation in EU competitive programmes is reserved for discussion in chapter 10. Greece has achieved a remarkable percentage of participation: the percentage of projects awarded to Greek R&D teams is much higher than the size of the research personnel employed in each respective field. On an average, Greece handles 3.5% of the EU competitive programmes, although it accounts only for 0.6% of the research population and 1.25% of the total population of EU. The figures for participation in international scientific publications are equally high – see table 10.3 in chapter 10.

7.6: Some important industrial and technology policy issues for consideration

Before proceeding with the examination of the Greek public and private materials strategies, some important considerations should be brought forward. The identified issues directly influence the characteristics of the Greek national system of innovation, and thereby the design and implementation of both national and corporate materials strategies and their connection, integration and compatibility with the overall industrial and technology policy conditions of Greece. The combination of many of these observations with the findings and recommendations of chapters 2-6 provides the basis for the development of a set of "working hypothesis" brought forward and tested in chapters 8, 9 and 10. Their aim is to analyse the Greek national and private materials strategies in order to provide findings which verify or contradict the central hypothesis of the thesis stated in chapter 1.

General considerations

The "final users" issue. The first major issue to be highlighted is the need for vertically integrated industrial sectors / clusters. As Kindis (1995) argues, one fundamental problem in the structure of many sectors of the Greek industry is the lack of vertical integration: the top elements of the value added chain are missing (e.g. large final user industries such as car manufacturing) to provide the necessary technology pull effect for smaller intermediate producers and materials or services suppliers. The role of the final users in Greece which can provide the necessary pull is held either by a declining number of multinationals and a large number of small producers (which do not manufacture heavily complex or sophisticated products) or by public enterprises which impose relatively low performance requirements or use international markets for sophisticated equipment.

On the other hand, with respect to the supply part of the chain, the Greek industrial policy of the 1960s and 1970s put emphasis on the earlier parts of the value-added chain (materials or components producers or intermediates) supporting the development of large and reliable units which have contributed to the establishment and growth of many other intermediate industries[40].

Based upon these considerations, the current Simitis administration put forward in 1996 its intention of promoting technological and industrial development on the basis of clusters of comparable/compatible firms which might share services or technological needs and feed-off each other, a policy that has worked well in many other countries (e.g. Portugal, Denmark, Norway). Moreover, within the EU, Greek industry has the opportunity to be a part of European vertically integrated production systems outside the "narrow" Greek borders. The Alcoa-Audi case study examined in chapter 4 provides a good example: the final materials user is a German car manufacturer but the materials supplier is a Canadian company. Greece has many industries on the materials supply side. The final user does not necessarily have to be Greek or located in Greece.

The technological intensity of Greek Industry. The second issue is the nature of the Greek industry. Many studies (e.g. Kottis 1980, Vaitsos and Giannitsis 1987, Korres

[40] The aluminium industry is a typical case: virtually all of the aluminium processing industry (e.g. structural materials and components for civil constructions, cans, foils, wires etc.) has been built on the back of the output of Aluminium De Greece, a very large materials producer, member of the French Pechiney group. But with few exceptions such large companies, or better groups of companies, are limited in Greece because the top elements of the value-added chain are weak or missing.

1995) have argued that the low to medium technology intensity character of the Greek industry is a serious source of obstacles for further industrial and technological development. Evidence from international experience contradicts this argument. Many countries, (such as South Korea, Taiwan, Spain, Israel etc.) started from this level and type of industrial structure. In later development stages they have progressed in high technology intensity industries but they also retained and updated many of their traditional industries (e.g. the construction sector in Japan, and the steel industry in Germany and the UK). Besides, even commodities are becoming high technology products which are and always will be in high demand or subjected to very slow substitution rates. As argued in chapters 2-4 a combination of corporate and materials competencies can transform low technology sectors into high technology sectors by offering both competitive advantage and operational efficiency. Therefore, the challenge for the Greek industry is to take advantage of the available MSE and other technological opportunities.

The issue of exports. A rather worrying trend is that Greek manufacturing exports increasingly target easy, "soft" markets and developing economies such as the Balkans, Eastern Europe, Africa, and Middle - East (ICAP 1994/96) rather than "demanding" and developed economies. In the short term "easy" markets provide easy profits and learning opportunities but the dynamic growth of these markets is time-limited because they will soon adopt and develop their own products or they will hit ceilings in their ability to pay. In technological terms these markets are not safe either, because firstly, they do not "teach" anything to Greek exporters and secondly, the exported products are the outcome of mature technologies which are widely available to anybody and therefore easy to copy. In technological terms, the real benefit of easy markets is the revenue they create, and the time they "buy". A part of this revenue can be channelled into R&D activities in order to support exports in "difficult" markets such as exports of high-added value products and services, technology, equipment, management, and know-how.

Regional and industrial development perceptions. Until the early 1990s policies of *regional development* received higher priorities nd they were using elements and initiatives of industrial and technological policies (e.g. the 1892/90 investment law – see chapter 8) as "implementation" instruments. To take the argument one step further, it is common policy of almost all Greek development and investment laws to subsidise the development of high technology industries or research activities in areas where basic or industrial infrastructure is completely inadequate to support the investment, while it practically "punishes" areas which are well-established hosts of highly structured, integrated industrial and technological clusters. Therefore, it can be argued that regional policies and the regional division of labour would do well to provide inputs and be complementary to the design of an overall national industrial and technology policy and not vice-versa.

The "fit" between industrial and technology policy priorities. According to the preceding information (section 7.3), the Greek industrial policies of the late 1960s and the early 1970s had adopted "top-down" approaches, as they practically enforced the nucleation and growth of specific industrial sectors. On the other hand, the technology policy priorities of the first two technology policy stages were focused on "umbrella" style horizontal priorities in order to improve the system's performance, eliminate its shortcomings and receive the much needed "feedback" about the conditions and potential of Greek industry. Consequently, the identification of specific fields and not just horizontal technological priorities introduced after 1994, was primarily identified by "bottom-up" approaches, that is received feedback from the domestic market-forces, which, in the case of Greece, are clearly weak and imperfect[41].

From the author's perspective, this "inconsistency" is a primary source for many shortcomings during both the design and execution of the national technology policies in Greece. If the two policies were to be complementary and achieve a long-term strategic "fit", specific field technological priorities should have been identified from the early stages of the national technology policies simultaneously or as a "follow-up" to the industrial policy selections and pursued simultaneously with horizontal measures as happened elsewhere (e.g. South Korea, Taiwan, Portugal).

The issue of technology transfer. The current technology policies in Greece give strong emphasis on technology transfer issues. Given the relatively low technological intensity level of many industrial sectors and given the initially limited R&D and technological capabilities of both public and private sector, there is a good rationale behind the concept to upgrade many sectors into technology "intelligent user" status. However, according to the findings of chapter 3, new technologies and their products or services are developed and diffused with considerably faster rates than 30 years ago. But in the 1990s, Greece does not have the luxury of time in the effort to first update its technological capabilities through technology transfers[42] and then develop new technologies. Technology transfer in Greece include the application, exploitation, and occasional advancement of existing knowledge and technologies - not emerging technologies which provide future competitive advantages. That approach has the

[41] According to preceding information (sections 7.3-7.4), the predominant "presence" of the Greek State in almost any aspect of the Greek economy has created considerable market imperfections or even distortions and weakened or strongly influenced the domestic market forces (Kalogirou 1991, Patsouratis 1993).
[42] As Japan, South Korea and Taiwan did during the 1950s, 1960s and 1970s.

potential to exclude or delay all emerging technologies and hence emerging materials technologies and their technological and economic potential.

Science/technology policy considerations

Many late 1980s and early 1990s evaluation reports (e.g. Giannitsis 1994, Polyzakis (1993, 1995), Pappa (1991, 1993), Planet 1994, GSRT (1991, 1993, 1995)) have identified the relative inefficiency of the national R&D programmes in terms of tangible results despite their application to near-market research. Various national innovation system shortcomings, bureaucratic and administrative flaws and policy issues have been identified as major sources of inefficiency. But these reports have not focused on the concepts behind individual policy elements and on the impact and consequences the execution *per se* of the national R&D programmes has on their effectiveness. The following observations highlight issues raised by both the character and the implementation *per se* of the national science/technology policy priorities and the national R&D collaborative programmes with respect to the impact they have on the design and efficient implementation of the national technology, and hence materials, strategies.

1) Given the *horizontal* character of the majority of the Greek technology policy priorities[43] and given the completely horizontal, non-discriminative and competitive nature of the national R&D collaborative programmes, the Greek science/technology policies were deprived of the ability to design and implement large scale "mission or application-oriented" R&D programmes from which many companies or industrial sectors could benefit simultaneously by sharing the benefits of pre-competitive research (see section 4.).

2) Given that the duration of funding of all major collaborative projects rarely exceeds 3 years all the major national programmes (e.g. PAVE, SYN, EKVAN) have a clear "competitive research" character. As such, all project proposals target the development of tangible products or services or the tangible improvement of S&P technologies which is regarded as achievable within the 2-3 years period of financial support. Therefore, the implementation *per se* of all the major national programmes can not sufficiently support pre-competitive and fundamental research activities. Under the present circumstances, and since there are no mission-oriented options, the

[43] During the first two stages (1984-1994) of its relatively brief history, Greek technology policies have primarily focused on complementary *but horizontal* priorities designed to correct the existing institutional and infrastructure shortcomings of the national innovation system, create a critical mass of both public and private R&D capabilities and provide a favourable environment for R&D activities. Even after 1994, approximately 74% of the EPET II's budget (see Table 7.7) is still allocated to horizontal priorities.

Greek national technology strategies risk becoming short to medium term endangering the long-term, R&D capabilities of the national innovation system. Moreover, the lack of centrally co-ordinated, mission or application oriented R&D programmes, has the potential to reduce the level of co-ordination (and thus effectiveness) of the application of the national technology priorities.

3) The issue of *technological consistency*. Given the current implementation arrangements, only the general priorities of the national R&D collaborative schemes are complementary (for example, PAVE opts for industrial and products development, PENED for human resources etc.). Given that there are no specific technological directions **cutting through all** national R&D schemes and since there is no central co-ordination of project allocation on the basis of specific technological directions there can be no medium to long-term thematic and technological consistency among the individual projects of each national R&D collaborative programmes[44] This problem of technology inconsistency and dispersion of resources generated by the implementation of the national technology priorities and the national R&D collaborative programmes, is probably the most important factor reducing the effectiveness of the national technology (and materials) strategies.

4) The lack of specific mission or application oriented projects (such as the Japanese JISADAI programme), the project competition-based allocation of funds for near-term time horizon, and the disproportional emphasis on competitive research discourage the formation of stable technology or research based consortia and long-term, technology-based alliances between corporations.

5) The allocation of R&D funds on the basis of project competition opposes any efforts for effective co-ordination and endangers the *division of R&D tasks* within the national system of innovation. Especially in the public sector the lack of sufficient public funds for R&D and the ability of all types or research organisations, including universities, to submit or participate in project proposals on the basis of free competition, has resulted in fierce antagonism and the collapse of research and technology division of tasks[45] (see chapter 8).

6) The competition based methodology of allocation of funds without the simultaneous application of thresholds, strategic controls or technological field pre-selections has the potential to create corporate (or even industrial sectors) technological *winners and losers*. Moreover, evaluations of the existing system, when

[44] This argument is further demonstrated in the case of materials in chapter 8.

[45]Research institutions for example, redirect their focus from pre-competitive to competitive research antagonising the technological institutions; universities are entering technological consultancies and in may cases laboratories or entire divisions are gradually transforming into research services provision companies.

used as "bottom -up" guidelines for the design of technology policy priorities, (and they *have* been used as inputs during the design of the technology priorities of EPET II), can lead to serious technology strategy imperfections because the needs of entire sectors which lost out in the projects "competition" (or simply did not to participate like the food industry), can fall out from the design of the national technology priorities. As such, technological priorities of crucial economic importance can be neglected or missed out completely.

7) Given that the current application of the national R&D programmes targets applied or competitive research, the results can not be shared by many industrial partners. As such, they are kept restricted (and in many cases officially unrecorded) by the company which contributes part of the project's expenses. This is a fundamental flaw of the Greek technology policies: in the case of Greece, it would be perhaps more advisable to promote the development of a set of enabling technologies[46]from which many companies or industries could simultaneously benefit, rather than supporting the development of single "products" from which only individual companies benefit. The present arrangements favour only the latter.

7.7: Key issues and findings

- State intervention has significantly assisted in the development of many industrial sectors and holds a central role in the development and evolution of the national system of innovation. It has distorted, however, the domestic market forces and has created institutional arrangements with unique characteristics.
- Industrialisation policies provided emphasis to the development of materials and components producers and not to intensive final materials and components users.
- Until the early 1980s Greek governments provided emphasis to industrial but not technological development. Until the late 1980s industrial policies were separated from science and technology issues.
- According to the findings of existing studies, until the late 1980s the majority of Greek industry had not sufficiently addressed management of technology and technology policy issues.
- The overwhelming majority of the national technology policy measures strongly focus on horizontal priorities. Pre-selection of technological priority fields was identified only since 1994. The implementation of the national technology

[46] Through mission oriented and specific technology application oriented R&D programmes.

priorities passes through the implementation of the national R&D collaborative schemes which also retain a strongly horizontal character.

- Both the character and the implementation *per se* of the national science/technology policy priorities provide issues for discussion and consideration with respect to the impact they have on the design and efficient support of both national and corporate materials strategies (see section 7.6).
- The national R&D infrastructure has been significantly improved during the 1985-1994 period. That is expected to have a positive effect on both national and private materials strategies.
- Academic and other research institutions hold a key role for knowledge creation, transfer and diffusion in the Greek national system of innovation.
- The Greek financial markets (banks in particular) have significant experience in financing industrial development but it is uncertain if they have extensively addressed the issue of financing technological innovation.

Finally, all the preceding evidence indicate that both the Greek economy and the Greek national innovation system are in *a state of transition*. With respect to the Greek economy, the process of privatisation in the public sector (begun in the early 1990s and is currently picking up momentum with the financial sector leading the way), the emergence of the services sector (which includes ITs, software and telecommunications), the large scale national infrastructure projects and the wave of mergers and acquisitions in the private sector, indicate that the Greek economy is entering a new era where advanced technology can play a significant role. With respect to the Greek national innovation system, since the early 1980s it is undergoing major *institutional and structural changes* aiming to build a strong science and technology infrastructure and R&D networks.

It is apparent that the Greek State has a predominant "presence" in the formation of both industrial and technology policies. Nevertheless, international experience has shown that in the materials case, and under specific conditions, this can be turned into an advantage (e.g. Korea, Japan, Taiwan, Germany, France, Portugal). Therefore, strengths, weakness and strategies identified in Greece can provide examples for other transition economies with similar structural/organisational characteristics such as the countries of Eastern Europe, Cyprus and the Balkan countries.

CHAPTER 8: Public strategies in Materials Science and Engineering technologies

8.0: Introduction and hypotheses

Chapter 8 addresses the Greek national response (public MSE strategies) to the Materials Revolution challenge. The purpose is to identify strengths and weakness of the current national materials strategies and of current institutions and organisational structures as they relate to the development of new technologies and materials within the Greek national system of innovation. The Greek national MSE strategies and priorities are reviewed and analysed on the basics of four logical entities:

1. Past and current MSE priorities and their rationale,
2. Supporting infrastructure issues (national research infrastructure dedicated to MSE, education and standards),
3. The role of universities and research institutes for the implementation of the national materials strategies, and,
4. Issues of financing technological innovation.

In order to achieve its goals chapter 8 poses and tests a set of four "local" working hypotheses based on observations and findings of chapter 7 (see sections 7.6 and 7.7).

Hypothesis H8.1: Given,

- the international examples of national material strategies adopted by small countries (see chapter 5),
- the characteristics and size of the Greek economy,
- the existing structure and conditions of Greek industry, and,
- the received feed-back and experience accumulated by the design and implementation of the national R&D programmes during the 1985-1994 period,

it is hypothesised that Greece would have established a 'selective' approach of national materials strategies with complementary MSE priorities which simultaneously aim:

(a) to address the development of enabling and generic materials technologies tailored to meet complementary MSE needs of related industrial sectors,

(b) to support sectors of national priority (e.g. energy production and utilisation),

(c) to create and/or support competitive advantages in niche areas and applications by exploiting and supporting established strengths in selected MSE fields.

Hypothesis H8.1 is analysed and tested by Annex 8.1. Key findings and observation and brief discussion on the verification or rejection of Hypothesis H8.1 takes place in section 8.1.

Hypothesis H8.2: Given the extensive restructuring and upgrading of the national R&D infrastructure and of the national system of innovation over the 1986-1994 period, it is hypothesised that the national MSE strategies/priorities would be effectively and sufficiently supported by:

a) The national R&D infrastructure
b) Patenting and standards policies
c) Higher education policies and continuous education schemes.

Hypothesis H8.2 is analysed in detail and tested by Annex 8.2. Key findings and observations and brief discussion on the verification or rejection of Hypothesis H8.2 takes place in section 8.2.

Hypothesis H8.3: Given that all of the national collaborative R&D programmes require the direct involvement of research organisations it is hypothesised that both universities and research/technological institutions would be performing a key role in the development and implementation of the national MSE priorities within the Greek national system of innovation.

Hypothesis H8.3 is analysed and tested by Annex 8.3. Key findings and observations and brief discussion on the verification or rejection of Hypothesis H8.3 takes place in section 8.3.

The issue of financing technological innovation is addressed by hypothesis H8.4a and H8.4b.

Hypothesis H8.4a: Given that the Greek State has provided finance with a long-term view for the support of the national R&D infrastructure (physical investments in R&D such as the establishment of new research institutes, subsidisation of the acquisition of R&D equipment etc.) it would be expected that it would also have established sufficient mechanisms for the financial support of R&D and technological innovation.

Hypothesis H8.4b: Given the special characteristics in which the Greek financial markets were developed (e.g. protectionism, heavy regulation, strong State intervention) it would be expected that they have different perspectives from their international counterparts on the issue of investing in technological innovation. Given the history of the Greek financial markets (banks in particular) in supporting industrial development it would be expected that at least those segments of Greek financial markets operating under public control would favour the finance of technological innovation.

Hypothesis H8.4a and H8.4b are analysed and tested by Annex 8.6. Key findings and observations and brief discussion on the verification or rejection of Hypothesis H8.4a,b takes place in section 8.6.

In addition, by using the materials case as a testing case, chapter 8 has the opportunity to pose the basis for testing an additional hypothesis with wider science/technology policy implications.

Hypothesis H8.5: Given that:

a) all national science/technology (and materials) priorities are implemented through the design and application of the national R&D collaborative schemes,
b) the competitive and the non-discriminative character and implementation approach of the national R&D collaborative programmes,
c) the observations and findings of chapter 7 (see sections 7.6 and 7.7) on the implementation of the national R&D collaborative programmes such as the lack of centrally co-ordinated mission or application oriented R&D projects within the Greek national system of innovation

it is hypothesised that the current technology policy implementation mechanisms of the Greek national innovation system cannot efficiently support the national MSE priorities because they:

- create issues of thematic consistency (see section 7.6)
- have the potential to create problems of division of R&D labour within the Greek system of innovation,
- have weakened (or have the potential to weaken) the pre-competitive and fundament research capabilities of the Greek innovation system, and,
- have the potential to exclude the participation of industrial sectors of major importance for the Greek economy.

Hypothesis H8.5 is expected to be verified or contradicted by the collected findings on both public and private materials strategies in Greece. Addition discussion and analysis takes place in Annex 8.4 and Annex 8.5. Sections 8.4 and 8.5 provide additional findings necessary for the testing of Hypothesis H8.5.

8.1: Key findings and observations on the Greek national Materials Science and Engineering priorities

During the 1986-1993 period, Greece had not officially formulated a set of national materials priorities. According to the interviewed officials, before 1993 the formulation of national materials priorities would be risky because technology policy designers did not have sufficient information on the needs of Greek industry and the capabilities of the Greek system of innovation.

The combination of the analysis of this period (presented in detail in **Annex 8.1** including statistical analysis, tables and figures) with insights into the outlines of the individual projects related to materials technologies (too difficult to be summarised in a thesis), some early findings of the technology foresight reports and other evaluation reports (e.g. Planet 1994, Giannitsis (ed.) 1994) leads to the following observations:

- Industrial interest is mainly focused on low-to-medium technology intensity and commodity materials, most of them incremental structural metals (both ferrous and non-ferrous) and ceramics (cements, refractories, consumer ceramics) and use of conventional, incremental and occasionally advanced structural metals, ceramics and polymers. In addition, the overwhelming majority of the industrial projects aim at the improvement of existing materials and processes.
- There is also industrial interest for specific advanced S&P technologies such as powder metallurgy, casting technologies, advanced surface treatments and optical fibers cable manufacturing which suggests that there are industrial segments which can take advantage of emerging materials technologies.
- Functional materials (mostly functional ceramics), advanced structural and functional materials and new materials research is the domain of interest of academic and research institutions.
- Information technology applications related to materials and S&P technologies (e.g. applications of IT for the automation of production processes, design of new products and organisation of production, and simulation and modelling) are the most popular sector of the national R&D collaborative programmes.
- There are materials classes and industrial sectors (e.g. wood, paper, textiles, leather) which appear to be isolated and with very low participation in both the national and international R&D collaborative programmes.

- The implementation of the national R&D collaborative programmes has failed to register the materials needs of some important industrial sectors (e.g. food and beverages industry, construction industry).
- The pre-competitive research oriented programmes (e.g. international programmes) are dominated by university and research institution participation. These participations have created research centres of excellence and accumulated scientific expertise on specific structural and functional materials classes (e.g. composites for aerospace applications and other advanced transport applications) which, in some cases, can be integrated either in the domestic or the EU market (see detailed analysis in chapter 10).

8.1.1: Contemporary Greek national Materials Science and Engineering priorities

The official declaration of targets and priorities of the national materials strategies is summarised below[1].

<u>NATIONAL MATERIALS STRATEGY (1994-1999)</u>

<u>Official Declaration of Targets and Priorities</u>

<u>Description of Targets</u>

Action 1.4 (materials technologies) of sub-programme 1 of EPET II, aims to develop and support technological activities in the area of **new and improved materials**. The implementation of the action is expected to create strong foundations which will support the gradual but dynamic re-direction of specific segments of the Greek economy, which have comparative or competitive advantages, towards the production of high - technology products, on par with the products of the technologically advanced nations. By taking into account:

- the current R&D infrastructure of the country,
- the special characteristics of national production systems (industry and services)
- the received feedback from the evaluation of industrial and research organisations participation in the national and international collaborative R&D programmes,
- some early results from the technology foresight initiatives (for some of the sectors),

the following materials sections / priorities were chosen:

[1] For presentation reasons repeated in Annex 8.1.

Materials Priorities

1) Advanced processing, production (manufacturing) and control technologies:

1. Advanced coating technologies: development and application of plasma-spray, laser deposition, chemical deposition, vapour deposition and multi-layers deposition technologies for the treatment and production of metallic, ceramic and composite based products / components performing in aggressive or demanding environments such as corrosive environments, high temperature environments, high friction environments, etc.
2. Development and application of powder metallurgy and advanced casting (continuous casting) technologies for the production of high precision components for various engineering applications.
3. Development and application of CIME, CNC, CAD/CAM, CAFM, robotics and advanced sensors technologies for the automation and quality control of production (manufacturing) processes of machinery and tools.
4. Development and application of non-destructive testing methods (such as acoustic emission and supersonics) for the diagnosis or the prognosis of damage or damage accumulation in structural materials, components or final products.

2) Development of improved or new materials for applications in:

1. *Building, construction and public works* (national infrastructure like roads, underground networks, railways etc.) such as the development of advanced fibers reinforced concrete, prefabricated structural elements, reinforced lightweight building elements, improved or advanced metallic, ceramic and other insulation materials for improved efficiency in heating and sound insulation of buildings and other large scale structures and for reducing construction and maintenance cost.
2. *Telecommunications and information diffusion:* emphasis on opto-electronic materials and optical fibers.
3. *Production, distribution, utilisation and storage of energy.* Emphasis is given on the development of advanced ceramics and refractors such as solid electrodes, semiconductors, and piezoelectrics for energy applications.
4. *Transport and agricultural production;* development of advanced polymeric materials for applications such as watering pipes, greenhouse panels and recreation sea vessels.
5. *Textiles, clothing and shoes.*

6. *Wood products.*
7. *Medicine*[2].

3) Materials and materials technologies for the protection and restoration of the national heritage and art works.

Development and application of advanced materials technologies in the maintenance, restoration and protection of the national heritage and art works from time damage and environmental pollution. Development of know-how for the employment of advanced materials during the restoration of ancient and traditional buildings and monuments.

4) Improvement of the efficiency of the construction industry with the substitution of "traditional" construction methods by in situ industrial style processes.

The aim of the initiative is the application of advanced building and construction technologies in order to optimise the in-situ construction process (by minimising time, cost and complexity) and in order to take advantage of the opportunities offered by new construction materials, especially the environmental friendly ones.

By combining and contrasting the national materials priorities with the analysis of the 1986-1993 period and the analysis of the 1994-1997 period (presented in detail in Annex 8.1, sections A8.1.2 and A8.1.3) the following key findings and observations on the Greek national materials priorities emerge:

1. There is a relatively good 'match' (or follow-up) between the identified MSE trends of the 1986-1993 period and the selected national materials priorities identified since 1994.
2. The national materials priorities are, in principle, addressing three parallel but complementary streams of action:
   - Materials and materials technologies tailored for specific applications or market niches (e.g. action 3: materials for the protection and restoration of monuments, and national heritage; action 2.4: special materials for agricultural and transport market niches).
   - Materials and materials technologies tailored to the complementary needs of specific industrial sectors (e.g. action 4: new technologies and materials for the construction industry; action 2.1: construction materials; action 4.2:

[2] It is not defined what classes of materials are involved ; functional materials is a possible assumption and the chemical industry can have a leading role in these efforts.

optical fiber technologies (for the cable & wire industry); action 4.3: ceramics for energy applications).

- Wide application (generic and enabling) materials technologies (e.g. action 1.1: surface treatments of materials for aggressive environments; action 1.2: sensors technologies, simulation, modelling and automation of processing and production lines; action 1.4: non-destructive tests for structural materials, components and other structures) which reflect common needs of many industrial sectors.

The first stream of action addresses relatively low/medium technological capabilities industrial sectors with the aim of transforming them into high technology sectors (e.g. action 2.1, 2.4, 2.5,6,7) and the second stream builds on the existing advanced materials capabilities of a handful of industrial units and research organisations (e.g. action 1.1 and 1.2). This arrangement is essential in order to avoid any potential marginalisation of a small but significant mass of leading firms and R&D teams.

3) The national materials priorities mainly concentrate on *structural materials* (especially *incremental* metals, ceramics and polymers). Functional materials are considered with caution since the domestic industrial capabilities and industrial demand are relatively limited to a handful of companies. As such, the national materials priorities target a wide spectrum of structural materials and a narrow spectrum of functional materials.

4) The structural materials priorities target common needs of technologically and commercially complementary industrial clusters or integrated materials producers - users systems[3]. It is also significant that under the influence of the recommendations of the technology foresight report the construction industry has been identified as an intensive final materials user sector of significant economic and technological importance despite its insignificant participation in the national and international R&D programmes. On the other hand, most of the functional materials priorities target niche markets and applications within the capabilities of the Greek science/technology basis.

In view of the above, it is evident that Greece has adopted a 'selective' approach of national MSE strategies with priorities which simultaneously aim: a) to the development of selected generic and enabling materials technologies tailored to meet complementary industrial needs and capabilities and, b) to create and/or support

[3] For example, see the complementarity between action 2.1: production of construction materials (metals and ceramics producers) and actions3 and 4: utilisation of these materials by the construction industry.

competitive advantages in niche areas and applications by exploiting and supporting established strengths in selected MSE fields. That *verifies two out of the three* conditions of hypothesis **H8.1** and proves that with respect to the selection of the national materials priorities *per se*, Greece **is** aligned to international experience (see chapter 5).

The condition which is not completely satisfied is related to national materials priorities aiming to support sectors of national priority (e.g. energy production and utilisation), or of strategic economic importance (e.g. the food industry). With respect to the satisfaction of this condition, the following weaknesses have been identified:

1) The national materials priorities have been designed almost exclusively on the basis of industrial interest measured on the basis of participation in national and international R&D programmes and not on the basis of a combination of market feedback and long-term strategic considerations. Hence, there is a strong possibility that the needs of strategically important industrial sectors have been neglected[4].

2) An additional source of consideration is the technological status of some of the final "recipients" of the materials priorities. GSRT has repeatedly identified incompatibilities between the standards of the submitted project proposals and the participation standards of the national R&D programmes. According to experts PS2 and PS1, GSRT's R&D standards are too high for some industrial sectors. Hence, it is questionable whether some of the targeted industrial sectors (as final users of the selected national materials priorities) are in a position to respond effectively to the emerging opportunities.

These issues receive further attention in chapter 9.

8.2: Supporting the national materials priorities: Key findings and observations

This section provides the key findings necessary for testing the second working hypothesis of chapter 8. Hypothesis **H8.2** states that given the extensive restructuring and upgrading of the national R&D infrastructure and of the national system of innovation over the 1986-1994 period, it is hypothesised that the national MSE strategies/priorities would be effectively and sufficiently supported by the national

[4] For example, there are priorities which are too narrow with respect to the significance and potential of their sector (e.g. action 2.3: ceramics for energy applications) while some other fields, such as fuel technologies and materials for environmentally friendly energy applications, are not involved at all.

R&D infrastructure, patenting and standards policies, and, higher education policies and continuous education schemes.

National R&D Infrastructure

A detailed presentation of the national materials R&D infrastructure (academic laboratories and research/technological institutions exclusively dedicated or directly related to materials technologies) is provided by **section A8.2.1** in **Appendix 8.2**. By combining this information with the findings of section 8.1, a number of findings emerge:

- Greece does not have any large scale research sites exclusively dedicated to MSE missions. The MSE field is served by eight (8) small Type II research centres[5], dedicated to a wide spectrum of materials fields. Apart from the Institute of Materials Science at Demokritos the two materials specialised technological institutions (metals and ceramics) are small to medium size, Type III technological centres with significant missions but limited capabilities (see analysis in Appendix 8.2). As such, both fundamental and applied research in the MSE field has to rely on small to medium size, widely dispersed research teams. In addition, there are no interdisciplinary MSE teams (e.g. a biomaterials centre) These arrangements impose additional limitations on the introduction of mission-oriented collaborative programmes and on the co-ordination of individual research teams.
- There is a problem of thematic consistency between the national materials priorities and the existing national R&D infrastructure. If we accept that materials strategies in Greece are tailored to meet domestic industrial (or economic) demand, then we expect that materials priorities would be adequately supported by the existing (or the under creation) national R&D infrastructure. But while the national materials priorities are mainly focused on structural and incremental materials, apart from the two small-medium size technological institutions and some university laboratories (usually consisting of small research teams of 5-20 people[6]) there are practically no other large-scale national research organisations dedicated to structural materials research[7]. Therefore, in their present form, the research objectives of the existing MSE infrastructure, *are not consistent with* the national materials priorities because they are oriented to a very different class of materials with different development and research characteristics and requirements.

[5] See section 5.3.3.: Research settings and mechanisms for co-operative research.

[6] Including the research fellows and the postgraduate (research) students.

[7] As we can see from *Annex 8.2*, all the research institutions are dedicated to functional materials, chemistry and chemical processes.

- There is a notable correspondence between the lack of academic and other public laboratories in some materials classes (e.g. wood and paper, textiles and leather) and the poor participation of the corresponding industrial sectors in both the national and international R&D collaborative programmes (see Table A8.2 in Annex 8.1). This point highlights the importance of the role of the Greek universities in the Greek national system of innovation and receives further attention below.

Hence, the national materials priorities are insufficiently supported by the limited number of the recently established Type III technological institutions and by university laboratories whose action under the present arrangements is very difficult to be aligned within centrally co-ordinated efforts. These findings **contradict the first condition** of hypothesis **H8.2** as the current national R&D infrastructure cannot sufficiently support the majority of the national materials priorities either due to lack of size/resources or due to thematic inconsistency of research interests.

Education Policies and MSE

A detailed presentation of education policies and MSE issues is provided by **section A8.2.2** in **Appendix 8.2**. The following are the most important findings.

- The MSE field is not officially recognised as an independent education field in Greece. Hence, MSE education at both undergraduate and postgraduate level is completely integrated with other science and engineering principles and directly related to scientific or engineering applications. This is viewed as a strength but, as direct result, the emphasis provided by undergraduate academic curricula on the four elements of the MSE tetrahedron varies considerably. Civil Engineering departments focus on properties, performance and S&P, Chemical Engineering departments on S&C and S&P and Chemistry and Physics departments on S&C and characterisation. Mechanical Engineering departments have the most rounded approach as they provide emphasis on all four elements of the materials tetrahedron.
- The great majority of the interviewed parties pointed out that the establishment of independent undergraduate MSE departments in Greece would be inappropriate[8]. However, they underlined the need to support the development of multidisciplinary and inter-departmental approaches at postgraduate level or the establishment of multidisciplinary postgraduate MSE departments.

[8] For detailed analysis see **Annex 8.2** .

- In addition, all the interviewed academics underlined that the improvement of MSE higher education in Greece is hindered by lack of sufficient funding for academic R&D infrastructure, and by a number of institutional shortcomings such as lack of efficient curricula evaluation mechanisms and lack of mechanisms for the support of R&D spill-overs (e.g. information diffusion networks, venture capital, "business incubators" etc.) within the Greek industrial base.
- Even though the MSE field is fully integrated with other science/engineering principles, MSE education is not recognised as a priority field by national education policies, neither at undergraduate nor at postgraduate level. According to the reviewed sources, the higher education system in Greece is clearly a *laisses -faire* system and does not provide or make suggestions for specific directions. The selection of specialisation fields is decentralised to the individual academic institutions or departments.
- The national system of State Undergraduate and Postgraduate Scholarships clearly discriminates against MSE principles (see section 8.4.2) as only a minute fraction of the annual budget is allocated to MSE Scholarships. Moreover there is no effort to create a system of undergraduate and postgraduate scholarships aiming to support the national materials priorities.
- In addition, the MSE field is inefficiently supported by technical and middle level technological education. All the interviewed companies pointed out that there is a serious deficit of skilled technicians and middle-level human resources which forces large companies to compensate with internal training schemes.
- Finally the MSE field is not sufficiently supported by management education and continuing education schemes (the latter are very weak and do not reflect the needs of the national materials priorities).

Apart from significant strengths originating from the complete integration of MSE education with other scientific and engineering principles all the other findings **contradict** the second condition of hypothesis H8.2 as the current arrangements (provision of directions, scholarships, technical education, continuing education) cannot sufficiently support either the national materials priorities or the MSE field in general.

Patents, Standards and MSE policies

A detailed presentation of patents and standards issues is provided by **section A8.2.3** in **Appendix 8.2**.

- According to the interviewed experts (public agencies), industry has a low interest in patenting R&D results and innovative ideas because they are related to small incremental improvements of either of materials and/or S&P processes (e.g. quality control or production efficiency improvements) which are difficult to patent and "easy to copy". These points were verified by the reviewed industrial sectors (metals and ceramics producers).

- There are no horizontal measures and incentives for supporting industrial patenting and/or standardisation strategies. In addition there are no financial and other horizontal incentives for the support of patenting academic and /or research organisations' R&D results. University departments or laboratories and research / technological institutions have to cover the lengthy and costly patenting process exclusively from their own budgets.
- Apart from quality control and assurance, the Greek State does not officially perceive patenting and standardisation strategies as an instrument of technological and economic advancement and as an instrument of harmonisation of Greek industry to cutting-edge technological developments. As such, the existing patenting and standardisation policies put emphasis on quality control, on safety and hygiene and on the production of conventional and incremental materials. They do not sufficiently address advanced materials issues (including testing and use of new materials) and the needs of many user industries (e.g. construction industry) on the basis of materials and processes systems.
- The efforts of both the Greek Standardisation Organisation and the Organisation for the Protection of Industrial Property (OBI) are hindered by internal problems such as lack of sufficient resources (human resources in particular) and by the institutional/operational framework of these agencies (ELOT in particular) dictated by the Ministry of Development.

According to the preceding evidence, there is a serious problem of adequate support of the national materials priorities by patents and especially standards and certification policies. The weaknesses of the Organisation for Protection of Industrial Property (OBI) are connected with "marketing" efficiency weaknesses originating from materials strategic concepts problems rather than serious policy problems. On the other hand, ELOT's weaknesses are related to policy restrictions and capital shortages imposed by its operational framework and the Ministry of Development. The lack of standards policies on the basis of national technological priorities and the lack of horizontal measures in support of academic and research organisations patenting and standardisation activities are the real source of the problem. They are identified as fundamental weaknesses of the Greek innovation system.

These findings **contradict the third condition** of hypothesis H8.2 as they strongly indicate that the current patents and standards policies and mechanisms have reached their efficiency ceilings and cannot sufficiently support either the majority of national materials priorities or the development of an 'aggressive' national MSE strategy in the future. For an infrastructure issue such as standards, it should be cleared that unstructured policies would have a detrimental impact on the ability of Greece to keep in touch with international developments and seek technological leadership.

In view of the above, the demands of the second hypothesis **(H8.2) have not been met** and the hypothesis is rejected. The national MSE strategies/priorities are not sufficiently supported either by the national R&D infrastructure, patenting and standards policies or national higher education policies and continuous education schemes.

8.3: National materials strategies and the role of universities and research / technological institutions: Key findings and observations

This section provides the key findings necessary for testing the third working hypothesis **(H8.3)** of chapter 8, which refers to the role of universities and research / technological institutions in the development and implementation of the national MSE priorities. A detailed analysis of the section is provided by **sections A8.3.1** – universities and **section A8.3.2** – research / technological institutions in **Appendix 8.3**.

The synthesis of the findings of the previous sections of chapter 8 pointed out that universities and research/technological institutions hold a key role for the design and implementation of national materials strategies for the following reasons:

- With respect to many emerging materials technologies, it is the Greek universities and research institutions which maintained links with international developments in many MSE high-technology intensity fields such as advanced composites and light alloys for structural applications, catalysis, photovoltaics and semiconductor research.
- Given the international exposure and the level of accumulated experience of the Greek academics, the influence of academia and research institutions is also reflected in the design of the national materials priorities: national materials priorities 1.1, 1.2 and 1.4 (see section 8.1.1) clearly reflect the potential and the interests of universities and research institutions.
- Given that the national collaborative R&D programmes require the participation of universities and research institutions, the connection of industry with academic

materials divisions and research institutions becomes crucial for the ability of a given firm (or even entire sector) to be aware of international developments and to be able to participate successfully in the national R&D collaborative programmes. There is a direct correlation between the absence of relative academic or research institutions activities in some materials classes (e.g. wood and paper, leather, glass, textiles) and the very poor record of successful projects proposals for the corresponding industrial sectors in both national and international R&D collaborations (Tables A8.2 and A8.4 in Annex 8.1).

Moreover, the analysis of the role of universities and research/technological institutions provided some additional findings:

- Given that there are no national mission or application oriented programmes the aims and the character of university and research/technological institutions materials research is almost exclusively dictated by the requirements of the collaborative projects or research contracts: most domestic collaborative or under contract research focuses on incremental structural materials, small improvements of established S&P technologies and simulation and modelling applications. Most international collaborative research focuses on structure and composition and properties of new and advanced materials such as advanced composites, catalysis and electronic materials.
- With respect to the materials tetrahedron, university research is primarily focused on properties, structure and composition and simulation and modelling applications rather than S&P and performance[9] for reason discussed in detail in Annex 8.3. However, all experts pointed out that there is a growing industrial tendency to introduce advanced S&P technologies even in commodity industries expected to make an impact on materials academic research.
- Given that both research contracts appointed by domestic industry and the national R&D collaborative programmes focus on applied or near market research, both universities and research/technological institutions have practically shifted away from pre-competitive research. Given that there are no mission-oriented national R&D projects pre-competitive research is involved in a limited number of international collaborative projects.
- If research institutions R&D results are not directly connected to projects which involve at least one final industrial user, it is very difficult to create products or services out of these results due to severe lack of appropriate supporting mechanisms and financial incentives (e.g. lack of venture capital for high-tech

[9] Similar conditions to the 1980s and early 1990s USA academic research.

start-ups - see below). For the same reasons both academic and research/technological institutions cannot act as start-up incubators.

Further, the analysis of the role of research/technological institutions provided some additional findings:

- Technological institutions have to provide integrated solutions to problems. Hence, materials research involves all four elements of the materials tetrahedron and compared to academic projects, puts particular emphasis on S&P issues.
- Structural, incremental materials account for the majority of the technological institutions R&D activities while functional materials (ceramics such as catalysts and electrolytes) account for 15-20% of RI2's activities.
- The R&D portfolio of both RI1 and RI2 is oriented to serve the specific interests of individual companies and not entire industrial sectors. Regularly, (especially in the case of RI1) these interests, take the form of trouble-shooting rather than real R&D.
- Due to institutional and operational limitations technological/research institutions can neither design and implement application or mission oriented programmes nor act as major implementation instruments of the national materials priorities. That limits their ability to focus on enabling and generic materials technologies, widely diffuse the results, and to stimulate industry to take on long-term R&D efforts. As side effects of these conditions:
  - The diffusion of technology and information is minimised and its efficiency is questionable because the R&D results become the property of individual project sponsors and not widely available to industrial sectors.
  - Since the major financial sources of these institutes comes from projects and contracts there is very little surplus to be invested in core competencies such as technology adaptation mechanisms and information gathering and technological evaluation units.
  - If technological institutions become too much market-driven, the danger of a downgrading of their technological abilities to simple services provision is apparent.
- Given the present conditions, the strategic mission and functionality of the research and technological institutions in the Greek national innovation system have been found to be weak in a number of respects: if the technological institutions continue to operate under the same specifications, and given that research institutions (such as Demokritus and CRES) are rapidly moving in the

direction of the provision of services on competitive research, then Greece risks to lose the services of Type II and III R&D organisations able to sustain pre-competitive and fundamental research. According to expert RI2, if the present circumstances are prolonged, the option of developing new materials, which requires Type II & III research organisations will become un-achievable.

The preceding findings **verify** hypothesis **H8.3** and point out that both universities and research/technological institutions hold a key role for the design and implementation of national materials strategies within the Greek national system of innovation. The same findings however, reveal that under the present institutional arrangements both universities and research/technological institutions have reached their contribution limits to the design and implementation of the national materials strategies and to the Greek national system of innovation and the Greek economy. If their potential is to be further developed, additional institutional changes must occur first.

8.4: Materials Science and Engineering and the implementation of the National Collaborative R&D Programmes (NCRDP): Key findings and observations

This section provides the key findings necessary for testing the **fifth (H8.5)** working hypothesis of chapter 8. Detailed analysis and discussion takes place in **Appendix 8.4.** The synthesis of the findings of all the preceding sections combined with the interview results and the analysis of the available data (see sections 8.3-8.5), provided the following findings on the impact of the implementation mechanisms of the NCRDP on the Greek materials (and technology) strategies.

The implementation of the NCRDP had many, general character, positive effects on the national innovation system of Greece from which the MSE field has also benefited:

- They have created links between research organisations and industry, some of which took the form of unofficial but stable and frequent technological collaborations[10].
- They have provided capital for materials R&D which otherwise would have been allocated to other activities.

[10] Usually, a firm (or a group of firms under common management) use as research partner the same university or research institution division or laboratory on a regular basis over a long period of time and for many project proposals.

- They have financed the infrastructure (experimental apparatus, machinery, etc) of many materials laboratories.
- They have created a substantial "pool" of specialised human resources and have familiarised R&D personnel with international experience and the performance requirements of high-standards of research in emerging materials technologies.

However, the horizontal character and the non-discriminative, competition-based implementation of the NCRDP which is not centrally co-ordinated and does not include budget thresholds for each of the national technology priorities and the short-to-medium duration of each individual collaborative project (3-4 years) has created a number of shortcomings in the Greek system of innovation. The MSE case illustrates that:

- The application of the NCRDP does not take into account the special requirements of the MSE field (or any other technological field).
- The implementation *per se* of the NCRDP has created problems of thematic and technological consistency problems (there are no thematic or conceptual co-ordination cutting through all NCRDP involving MSE activities - see Tables A8.2 and A8.4 in Annex 8.1).
- The competitive nature of the NCRDP inhibits the formation of R&D consortia and long-term technological alliances and deters the formation of collaborative industrial networks. When stable but un-official R&D consortia are formed, these cases are the outcome of management choices of the participants and they exist as long as the NCRDP exist.
- Even though many of the national materials priorities target complementary industrial sectors, the implementation of the NCRDP does not promote collaborations between interdisciplinary or complementary industrial sectors.
- The majority of the approved projects include (if any) only one or two industrial participants as the final R&D results users. Hence, individual firms benefit but the development of generic technologies is inhibited and no wide and substantial technology transfers, spill-overs can be expected on industrial sector level.
- The materials case illustrates that R&D in materials technologies has become multi-organisational but not inter-disciplinary (or multi-disciplinary). The NCRDP are deprived of the concept of promoting or supporting inter-sector activities, and, in general, technology fusion efforts.
- The relatively low-budget and short-to medium-term character of the projects of the NCRDP *deters* the submission of proposals targeting pre-competitive research

or the development of new materials. Further, given that participation in the NCRDP is a matter of crucial financial importance for the Greek research organisations, both universities and research institutions (see the case of CRES in Annex 8.3) refocus their R&D portfolios on applied and near market (materials) research. Hence,

* the *R&D division of labour* within the Greek system of innovation is *de facto* disrupted.

* there is a visible danger of a serious erosion of the abilities of the Greek innovation system in pre-competitive (materials) research, which has the potential to deprive the country of the ability to design and apply long-term R&D materials strategies in the future.

- Finally, there are strong indications that the implementation of the NCRDP create technological "winners" and "losers" at both corporate and industrial sector level. This point receives further investigation in chapter 9.

According to the above, the existing settings of the R&D collaboration system in Greece are neutral or even favour some short-term technologies (e.g. software development, applications of simulation and modelling in materials technologies and other fields), while they have a negative impact on long-term, complex, and enabling technologies such as materials technologies.

In the materials case, the implementation of the NCRDP is unable to support the development and commercialisation of new materials, of new or radically improved S&P technologies and technology-based diversification or technology fusion strategies. On the contrary, it favours the improvement of incremental materials, simulation and modelling activities, software developments, and localised S&P efficiency improvements but not the development and commercialisation of advanced materials and emerging technologies.

These findings **verify** the first three conditions of **hypothesis H8.5** as they point out that the implementation *per se* of the national technology and materials priorities going through the implementation of the NCRDP, has created problems of thematic consistency, endangers the division of R&D labour within the Greek system of innovation and weakens its ability to design and implement pre-competitive research activities. In addition there are strong indications that some industrial sectors have been marginalised by the implementation of the NCRDP. This point is further investigated in chapter 9.

Further, these findings have wider implications: given that the NCRD programmes are the major instrument for the implementation of the national technology priorities, the selection and implementation of the national materials priorities is restricted by the implementation of the NRDPs. The above *constitute key findings* by the author in this chapter. All previous R&D evaluation reports in Greece have invariably missed these issues.

8.5: Supporting governmental policies: Key findings and observations

Detailed analysis and discussion of the section takes place in **Appendix 8.5.**

- The monitoring and supervision of the execution of NCRDP is under GSRT's jurisdiction. GSRT met the desirable level of monitoring and supervision only for the pre-1993 period. Since 1994, mainly due to the large volume of the submitted proposals and lack of internal resources, monitoring and supervision of the projects of the NCRDP *was restricted to financial auditing alone.* In addition, with respect to the overall supervision and co-ordination of national R&D activities, GSRT has not met the desirable level of co-ordination mainly due to administration and co-ordination imperfections beyond GSRT's jurisdiction.
- With respect to the creation and support of R&D infrastructure, the Greek innovation system, during its early stages, was designed to create R&D winners. Materials R&D infrastructure was favoured both during the design and implementation of STRIDE and EPET I and by "top-down" measures inspired and implemented directly by GSRT and the Ministry of Development. At corporate level, the system of directly allocating R&D funds on the basis of projects uses a combination of the market forces and the imposed evaluation criteria as a mechanism of "natural selection" for picking (or creating) R&D champions.
- A serious deficiency of the Greek innovation system is the way in which R&D data (and other technological information) are collected, recorded, evaluated and diffused. With respect to MSE, a specialised agency dedicated to the monitoring and evaluation of materials technologies like, say, The Institute of Materials in London, UK, does not yet exist.
- An additional serious deficiency of the Greek innovation system is the lack of export promotion mechanisms and commercial networks supporting the penetration of "hard" markets by high-technology Greek products.

8.6: Financing technological innovation in Greece: Key findings and observations

This section tests the fourth hypothesis (**H8.4a,b)** of chapter 8. The following findings (derived from detailed analysis in **sections A8.6.1** to **A8.6.3** in **Annex 8.6**) put first to the test the hypothesis H8.4a that the Greek State would have established sufficient mechanisms for the financial support of R&D and technological innovation. It then put to the test the hypothesis that the Greek financial markets would have different perspectives from their international counterparts on the issue of investing in technological innovation and that at least those segments of Greek financial markets operating under public control would favour the finance of technological innovation.

The role of Government

- The financing of R&D infrastructure in Greece has always been dominated by the strategic investment concept aiming to develop or support the science/technology capabilities of the country. However, both direct and indirect capital allocation for R&D activities in the form subsidies, tax incentive or procurements is usually directed to updating of R&D equipment, or the development of "physical" R&D facilities such as R&D laboratories. But the use of equipment involves human resources and ongoing expenditures. That kind of R&D expenditure is poorly or not subsidised in Greece.
- From the author's perspective, the failure to distinguish and equally support the two separate but inter-connected issues, contributes to the limited effectiveness (in terms of tangible results) of many public efforts for supporting the finance of technological innovation in Greece.
- Until the early 1990s, public contracts, procurements and the concept of 'market securitisation' were used only as instruments of industrial and regional development. There were not consciously used as instruments of technological development.
- Greece has not developed an efficient set of tax incentives for the support of pre-competitive and applied industrial research. In the place of tax incentives, there are capital subsidies (the investment law 1892/90 and its supplementary modifications) but only in the form of industrial development support and on the basis of supporting the application of existing knowledge in order to produce tangible products and services.
- The investment law 1892/90 and its later modifications and supplements is primarily an instrument of industrial and regional development policy designed to

support large scale, high-technology, product, process or services projects. It is the first industrial development law which, in spirit, introduces the concept of technological development in parallel with the concept of industrial development and the concept of financially supporting reverse engineering activities in Greece. However, the spirit and the application of the law has six serious drawbacks:

- ✓ It provides more emphasis to regional development rather than technological development.
- ✓ It shifts attention from exports to imports substitution which, in the long run, is an anti-motive for technological advancement.
- ✓ It provides emphasis to technology transfers and small development/evolution of established technologies for production (and primarily import substitution) of high technology products or services.
- ✓ The implementation of the investment law, like the implementation of the NCRDP, does not differentiate between technologies (hence no special arrangements for materials technologies).
- ✓ The incentives of the 1892/90 law focus on generic measures designed to support industrial sectors or wide technological fields. According to the findings of chapter 6 (section 6.3) these horizontal character arrangements are necessary for creating a supportive environment for all technological fields but they cannot efficiently support specific technological priorities.
- ✓ The law is not designed to support R&D spin-offs or high technology start-ups.

The role of banks

Banks under State control have very little to do with the financing of technological innovation in Greece. Their involvement is rather indirect and circumstantial and is underscored by the credibility and financial strength of the applicant which is usually, a large, well-established, corporation. High-technology SMEs are largely left out of investment opportunities. In more detail:

- The reviewed banks (the commercial ones in particular), admitted that they were not aware about the strategic and financial potential of many technologies including materials technologies.
- For investments in high-technology areas subjected to the statute of the 1892/90 investment law the State controlled banks operate within the directives of the investment law. During the evaluation stage of a proposal, banks concentrate on the business characteristics of the proposal, financial sizes, market conditions and credibility issues. Technology evaluations are usually received by the high -

technology evaluation committees of the Ministry of Development. When an investment proposal is approved, banks are obliged to provide loans or investments under better terms[11] but it is to their discretion to decide on insurance measurements and exit mechanisms.

- With respect to free-will investments banks admitted that they did not have in place specific policies for financing technological innovation portfolios. They also admitted that they did not have in-house mechanisms to effectively analyse and evaluate technology-based projects or help them prioritise among technological fields.
- In general, banks avoid investing in projects directly related to technological innovation. If a technological innovation related investment application is approved, it usually involves low-risk technological targets such as product improvements, new plants, expansions, introduction of new products or services produced by established technologies and technology transfers or acquisitions. There is no discrimination or prioritisation between technologies or industrial sectors.
- Investment applications are evaluated on the basis of the financial credibility of the applicant and other tangible evaluation criteria such as tangible assets of the applicant, fixed capital, annual turn-overs etc. Commercial banks put more emphasis on finance/economic indicators while investment banks give priority to evaluations of the credibility of the applicant and the credibility of the proposal (see also Table A8.15 in section 8.8.2).
- Supervision/monitoring of the investment takes place through techno-economic auditing or by appointment of bank managers in the management board of the beneficiary company.
- Both commercial and investment banks admitted that they have very little or no communication at all with "pockets of research excellence" or with university and research institutions.
- Both commercial and investment banks pointed out that they were considering to become more active in financing technological innovation projects giving priority to telecommunications and high-technology services sectors. Materials technologies were not among those considered.

[11] With respect to free-market investment proposals.

Venture Capital

Venture capital in Greece was institutionalised only since 1988. In 1996 there were four venture capital companies. Their operational characteristics were similar to the operational characteristics of EU and UK Venture Capital companies. In more detail, the analysis of three out of the four venture capital companies in Greece showed that:

- The Greek VC companies neither focus on specific technologies nor exhibit any preference for specific industrial sectors. Their investment portfolios were spread over many industries and technological fields.
- As the Greek banks, for the evaluation of technological information, VC companies rely almost exclusively on external resources (mainly guidelines provided by GSRT or the 1892/90 investment law). They have not developed in-house mechanisms for evaluation or prioritising among technologies and technological fields.
- VC companies admitted that they have very little or no communication at all with "pockets of research excellence" or with the university and research institutions.
- Investment proposals are usually evaluated on the basis of the proposal's commercial and operational reliability, the credibility of the submitted business plan, market parameters (including commercialisation networks), management skills of the applicant and tangible assets of the applicant. Technological considerations are the last ones to receive attention.
- Within this framework, VC companies in Greece prefer to invest in low technological risk projects such as products and processes improvements, expansions of established companies and new product introduction or product diversification projects supported by well established applicants.
- There is a serious lack of capital for high-technology start-ups and for academic research spin-offs and for the first growth stages of high technology SMEs. In addition the business angels concept has not yet been institutionalised in Greece.
- The Greek State does not provide compensation for these financial markets imperfections. The established agencies aim to manage or attract large scale investments (Direct Foreign Investment) directed to industrial development. Until 1997, there were no public agencies with the mission to provide or secure financial support for technological innovation and high technology SMEs.

Finally, F1, F2, B2, VC3 and VC2 underlined that a major obstacle for financing or effectively supporting the finance of technological innovation in Greece is the lack of a centrally co-ordinated strategy to synchronise public agency activities and provide guidelines to financial markets in the form of suggestions and recommendations[12].

According to the above, both **hypotheses H8.4a and H8.4b** have been **rejected**. With respect to hypothesis H8.4a, the Greek State **has not** established sufficient institutional public mechanisms for the financial support of R&D and technological innovation apart from the design and implementation of the national R&D programmes. All the strain falls on the shoulders of the Greek financial markets which are as yet unprepared to take full loading. **This void is identified as probably the greatest weakness of the national innovation system in Greece**.

So far Greece has attempted to fill this void with appropriate legislation measures. However, legislation **cannot** substitute the need for an industrial and technology strategy and mechanisms for finance. Legislation is a tool for the implementation of strategic choices and for the institutionalisation of mechanisms and procedures. Legislation alone can neither create mechanisms and procedures, nor substitute for the value of a long-term strategy.

Hypothesis H8.4b has also been rejected. Despite their experience in financing industrial development, institutional investors and financial markets in Greece are in principle distant or very cautious to be extensively involved in the financing of technological innovation because they are *either unaware or unprepared to cope*, or because they still "suffer" from burdens inherited from their past and cannot yet afford the involved risks. In addition, the investment behaviour of the Greek institutional investors resembles the operational characteristics of many EU counties and other international institutional investors despite the special characteristics in which the Greek financial markets were developed. With respect to financing technological innovation, both banks and venture capital companies evaluate proposals on the basis of the applicant's size, financial credibility, real assets, market considerations and other tangible indicators rather than on the basis of technological considerations or considerations directly related to the involved technologies and their commercialisation prospects. Moreover, the Greek institutional investors appear to have serious problems in evaluating technological information and technological risk, as many of their international colleagues, despite their experience in financing industrial development.

If these trends continue, despite the Greek financial markets reformation wave, enabling and infrastructure technologies such as materials technologies will be

[12] See for example the UK Chancellor's announcement in 1998 for a public fund of £ 240 million in support of venture capital activities in the fields of electronics, telecommunications and biotechnology.

omitted from future strategic and investment considerations and Greece will be denied the capability to effectively support the finance of technological innovation.

8.7: Conclusions and final observations

According to the preceding evidence the achievements of the national materials (and technology) strategies include:

1. The gradual introduction of national technological and materials priorities,
2. The conscious pursuit of all four elements of the materials tetrahedron in all R&D collaborations which include industrial involvement,
3. The establishment and strengthening of links between materials research organisations (universities - research institutions) and industry,
4. The "creation" of both research organisation and industrial R&D "winners" ,
5. The establishment of a new R&D mentality in many materials producers and users,
6. The gradual establishment of the strategic importance of the MSE field.

The national technology (and materials) strategies fail in the following respects:

1. In the provision of supporting policies and mechanisms for the assistance of the national materials priorities (e.g. education policies, standards policies, financing technological innovation mechanisms, technological information diffusion mechanisms).
2. In the implementation arrangements of the national technology and materials priorities and the NCRDP which have reached their limits in terms of effectiveness.
3. In the total absence of centrally co-ordinated, large scale pre-competitive R&D projects,
4. In policy administration and co-ordination issues,
5. In the provision of effective support of long-term R&D mechanisms,
6. In the establishment of industrial networks and the promotion of industry to industry co-operations.
7. The Greek institutional investors appear uninformed and uninterested or unprepared to support the national materials priorities.

This evidence indicates that successful concepts are continuously derived from international experience, but paradigms of their implementation are not. To make a connection with the findings of chapters 1, 2, 5 and 6, since 1994, the Greek national materials strategies do not fail the concept of identifying national materials priorities (a fundamental international "code of practice") despite the identified weaknesses of the national system of innovation. Indeed, with respect to the selection of the national materials priorities and the parameters taken into consideration for their selection, Greece appears to be aligned with international experience.

An additional positive development is a conscious effort by the settings of the major national R&D programmes to provide equal attention to all four elements of the materials tetrahedron (S&P in particular) and a remarkable awareness of all the interviewed parties of the importance of the materials tetrahedron regardless the current R&D approaches. Hence, the first level (technological level) of the “international codes of practice” has also been satisfied.

Nevertheless, an important finding is that a potential source of concern is that the majority of the national materials priorities mainly target incremental structural materials (mostly metals and ceramics), advanced but established S&P technologies and a very narrow range of advanced structural and functional materials priorities.

This is a reasonable selection because the present arrangements of the Greek national innovation system (the implementation of the NCRDP in particular) **are unable** to efficiently support an aggressive new materials and new technologies development approach. In other words, Greece, fails the concepts of efficiently supporting, implementing and supervising the national materials activities which are an integrated part of the third level of the materials international "codes of practice".

The Greek contemporary national materials priorities are restricted by the accomplishments and shortcomings of the Greek national innovation system as it has evolved during the last 15 years of its re-design and re-definition and they are **let down** both by the way they are executed and by the way they are supported by institutionalised mechanisms such as education and standards policies, infrastructure policies, mechanisms supporting and financing technological innovation etc.

Therefore, an important finding is that if Greece wishes to pursue more aggressive materials strategies (development and commercialisation of new and advanced materials and S&P technologies) and to efficiently support them, *considerable additional institutional changes have to occur first or simultaneously take place* with the design of the new/additional national materials priorities.

Finally, the synthesis of the available findings provides the opportunity for two additional observations:

Many of the identified problems of the national system of innovation are possibly related to existing perceptions and thus education background problems of the political leadership and the occasional policy makers[13] responsible for the design and the settings of the national technology and materials strategies. Section 8.4.2 argues in detail that Greek higher education has not yet addressed management education on the basis of a combination of technology-finance- management principles. That is where the arguments of chapters 4 and 5 and of Chelsom, Dennis, and Kaounides (1994) and Chelsom and Kaounides (1995) in favour of holistic education reveal their value.

Moreover, a deeper origin of the shortcomings of the national innovation system is related to the established condition of the Greek State and the Greek economy. As one of the interviewed experts pointed out,

> "... a national technology policy / strategy is (or should be) defined as the "output" of the conditions and structure of the Greek economy, industry, and State (governance and administration). As far as these conditions remain the same there is not much chance of significant technology strategy changes."

These are problems which are directly related with established perceptions and with the preservation of *existing balances of power* within the Greek State and the Greek economy.

[13] Tsipouri (1993) and Patsouratis (1995) have also identified that perception problems are a major sources of shortcomings for the design and implementation of technology strategies in Greece.

CHAPTER 9: Private Sector Materials Science And Engineering Strategies

9.0: Introduction and aims of the chapter

Chapter 9 addresses the private response to the MR challenge by reviewing and analysing current materials strategies in the selected materials producing (metals and ceramics) and materials using industrial sectors (see section 7.4). The chosen materials users (construction and defence sector) are the main domestic consumers of the output of the reviewed materials producers. Moreover, additional producer-user relationships exist within the reviewed sectors:

- The construction sector is the main consumer of the products of the cement, consumer ceramics and structural metals sectors;
- The defence industry including shipbuilding and maintenance is (potentially) the main consumer of structural metals, ceramic products (e.g. coatings), refractories and advanced ceramics produced in Greece;
- The cement sector, the consumer ceramics sector and basic metals producers are the main consumers of the products of the refractories sector.

Within this framework, chapter 9 poses a set of "local working" hypotheses (see below) and by testing them investigates whether the reviewed sectors are in a position to develop, and effectively support multi-levelled and sophisticated materials strategies as an integrated part of each firm's and sector's technology and business strategies. The findings of chapters 2, 3, 4 and 6 provide the main points of theoretical reference for this chapter. The following sections provide the most important **(key)** findings emerging from the analysis of the reviewed sectors. Detailed sector analysis including information on the characteristics and the operational environment of each reviewed sector is provided with **Annexes 9.1 to Annex 9.6.** Finally, chapter 9 concludes with a brief discussion on the verification or contradiction of chapter 9's "working" hypotheses, and the implications for private and public materials strategies in Greece.

Hypothesis H9.1: Materials Producers

Given that,

- the reviewed sectors (basic metals and ceramics producers) are dominated by large industrial units,

- they maintain a high level of continuous and successful participation in national and international R&D collaborative programmes (see sections 8.1 and 8.2),
- their R&D activities are supported by two dedicated research / technological institutions (RI1 and RI2),
- they have stable markets for their products, that is, their output is mainly absorbed by domestic consumers over long-periods of time,
- their operational activities are regularly subsidised by the Greek State (e.g. cheap electrical energy- see Kalogirou[1] (1991)),

It is hypothesised that these sectors would be expected to perceive MSE technologies as a basic requirement for competitive advantage and that they have developed (or they are in the process of developing) complex and sophisticated MSE strategies on the basis of the international "codes of practice" as identified in chapters 2, 3, 4 and 6. Variations with respect to the response of the reviewed sectors are expected.

Hypothesis H9.2: Materials Users

In the materials users case a different approach is followed. Kindis[2] (1982 and 1995) argues that a fundamental problem in the structure of Greek industry is the lack of vertical integration: the top elements of the value added chain are missing (e.g. large, technology-intensive final user industries such as car manufacturing) to provide the necessary market and technology pull-push effect for smaller intermediate producers and large materials or services suppliers[3].

By applying Kindis argument to the MSE field and the case of materials intensive users (such as the reviewed construction and defence industry) it is hypothesised that:

Hypothesis H9.2a: the defence sector, a highly sophisticated, advanced technology sector, has developed complex and sophisticated MSE strategies and would be in a position to provide the necessary technology-pull to materials producers and hence, in the MSE case, it is expected to contradict Kindis' argument.

Furthermore, given that the sector is an oligopolistic sector and it is continually subsidised by the Greek State, it is expected that:

The sector would have adopted long-term technology and materials strategies as it is not subjected to capital flow restrictions or operational risks related to the success or failure of long-term R&D programmes, and,

[1] Kalogirou, I. (1991). *The interlocking between the purchasing power of the State and industrial activity: The case of Greece.* PhD Thesis. National Metsovion Polytechnic, Athens.
[2] See Kindis, A. (1995). *Greece on the Threshold of the 21st Century.* Ionian Bank, Athens and Kindis, A. (1982). *The growth of Greek industry.* Gutenberg, Athens (in Greek).
[3] See also chapter 7, section 7.3.4.

Given the established international experience, the sector would have developed strong links with the national research infrastructure and the Greek academia.

Hypothesis H9.2b: it is hypothesised that the construction sector, a low-to-medium technology sector with a poor record of participation in the national R&D programmes and many sector related peculiarities (see the general characteristics of the industry in Annex 9.6) has not yet developed advanced MSE strategies and it is not in a position to provide the necessary technology-pull to materials producers, hence, in the MSE case, it is expected to *verify* Kindis' argument.

Moreover, the evidence assembled in the thesis provided the opportunity to present some additional findings:

To begin with, the cases reviewed can be classified as companies operating under mixed or Greek ownership/leadership and companies operating under foreign ownership or supervision (subsidiaries of multinationals). Given the ownership, size, and, potentially, differences in the management's perspectives, the thesis has the opportunity to examine if there are any materials strategy variations originating from this differentiation.

Hypothesis H9.3: It is hypothesised that there are significant MSE strategy variations between companies operating under Greek ownership and companies operating as subsidiaries of non-Greek multinationals.

Moreover, the NRC (1989) study on advanced materials technologies[4] found that there is a direct connection between the performance (in terms of domestic and international sales) of a corporation / sector and the level of its MSE strategies. The NRC study demonstrated that the USA industrial sectors which had developed complex materials strategies as an integrated part of their technology and business strategies retained or increased their competitiveness, whereas those that did not suffered severe losses. Chapter 9 has the opportunity to verify or contradict these findings on the basis of hypothesis H9.4.

Hypothesis H9.4: It is expected that the Greek case would verify the NRC (1989) study findings as described above.

Finally, given the findings of chapter 8 on the implementation of the national R&D programmes and schemes, and by using the case of MSE strategies as a testing tool, the thesis has the opportunity to test two additional hypotheses:

Hypothesis H9.5: Given the horizontal character of the national R&D programmes and collaborative schemes, it is expected that the participation

[4] US National Research Council (NRC) (1989). *Materials science and engineering for the 1990's: Maintaining competitiveness in the age of materials.* National Academy Press, Washington D.C.

preconditions and their implementation have excluded the participation of industrial sectors crucial for the welfare of the Greek economy.

Hypothesis H9.6: Given the existing co-ordination problems of the Greek national system of innovation and its recent history, it is hypothesised that its current institutional arrangements and mechanisms for the implementation of the national technology and materials priorities are designed to provide support only to individual sectors or firms. Moreover, we would also expect that the same arrangements would not have the effect of supporting complementary industrials sectors, networks, technological clusters and inter-sector collaborations.

The verification or contradiction of hypotheses H9.3-6 emerges through a combination of the collective findings of all the reviewed sectors.

9.1: Materials Producers: Ceramics - cement, consumer ceramics and refractories

The thesis analyses the ceramics producer sectors (cement, consumer ceramics and refractories industries) on the basis of the materials producers **hypothesis H9.1** which hypothesises that the reviewed sectors are able to successfully respond to the emerging technological and commercial challenges because they have developed multi-levelled and sophisticated advanced materials strategies as an integrated part of their technology and business strategies.

9.1.1: Cement and related industries

The Greek cement industry is a mature and oligopolistic sector exporting approximately 50% of its annual produce to EU and other countries (see also Annex 9.1). Until 1989, all the major production units of the sector were operating under Greek ownership and leadership but today only one remains in Greek ownership.

The thesis reviews the two leading companies (C1 and C2) of the sector producing more than 80% of the annual domestic cement production and more than 85% of its by-products. **C1** is a medium size corporation when compared to its international competitors, while **C2** is a large cement and other construction materials producer operating since the early 1990's as a major unit of an international giant specialised in the production of structural and construction materials. A detailed analysis of the sector including its basic operational characteristics is presented in **Annex 9.1**.

Corporate Strategies and Materials Activities

The detailed analysis of the sector demonstrates that the Greek cement sector perceives MSE competencies as a crucial determinant of its current and future competitiveness. Both reviewed companies have developed multilevel and sophisticated MSE strategies completely integrated with their R&D, technology and business strategies including both the improvement of incremental materials (C1 and C2) and the development of new advanced materials (C2 only).

** Both companies export approximately 50% of their annual output in both conventional and technological demanding markets and they have the intention to increase their exports within the next 10 years. C1 focuses almost exclusively on cement and cement by-products while C2 follows a much more "aggressive" business and technology policy including gradual diversification in a wider range of cement and other ceramic based construction materials and markets. C2 pursues this policy with the assistance of a group of subsidiary companies (SMEs) specialising in niche markets and applications.

** With respect to *production and manufacturing* technologies both companies place emphasis in the strategic acquisition and transfer of state of the art technology from international sources (*intelligent users of advanced technology*).

** The technology strategy of C1 focuses on keeping the company at the forefront of international technological developments, while its materials strategy focuses on the improvement of existing materials (as products or as enabling tools for S&P improvements) or the introduction of new but established materials into demanding (but established) markets.

** On the other hand, C2 is not subjected to the size and financial limitations to which C1 is subjected and pursues *both* the improvement of incremental materials (mainly cement and cement products) and technologies and the development of totally new materials (structural ceramics for construction applications) in order to support its product and business diversification strategies with product, S&P and other technological innovations. Simultaneously with its diversification strategies, C2 has developed and deployed a strategy targeting not only an operational but a MSE-based vertical integration including raw materials production (used for cement and other products) and the acquisition of construction companies employed in the commercialisation of new products and materials.

** In order to support their materials and technology strategies and their business objectives both C1 and C2 have established corporate R&D laboratories and specialised MSE laboratories and divisions. The portfolios and the basic aims of both the corporate and the materials R&D divisions are tailored to support each company's technology and business needs (third generation R&D) and satisfy customers' needs. They are presented in detail in Annex 9.1. In addition, some of the subsidiary companies of C2 also have limited R&D capabilities and they contribute to the collective accumulation of know-how.

** Materials R&D focuses *equally on all four* of the materials tetrahedron elements and it is extensively supported by simulation and modelling techniques. C2 also evaluates and considers a small range of *functional* materials but only as a secondary option and always within joint venture schemes. The average R&D project duration however, is no longer than 1-2 years in the case of C1 and 2-3 years in the case of C2, which reflects the resources or the time constraints faced by the industry.

** Finally, both companies have reverse engineering and technology adaptation capabilities dedicated to integration and/or improvement of externally acquired technologies and materials know-how.

Management practices and core competencies

Both companies stated that they are consciously committed to the concept of Kaizen and that they optimise their operational activities using Kaizen management techniques. In addition, while the industry only occasionally employs some Kaizen elements (e.g. SE during the design of their technology and business portfolio), it has been the Greek pioneer of some others (e.g. team-work and human resources policies).

In addition, both companies identified as their primary core competency their product and market *credibility* (brand-name / trade mark) and their ability to technologically support this credibility over long periods of time. C2 added the ability of the company to diversify its activities on the basis of its technological strengths.

Financing Technological Innovation and R&D

Both companies perceive technological and R&D investments as an absolutely necessary long-term strategic investment and finance their technological and R&D activities primarily using their own resources (especially when sensitive research is involved). Moreover, each company monitors both their operational and their R&D activities employing a combination of strategic and financial controls.

9.1.2: Refractories and Commodity Ceramics

The materials and technology strategies of the refractories and consumer ceramics sectors are reviewed together, even though their products target totally different final user industries. This is because the two sectors share many common technological needs and characteristics and because their products display certain common features which, on the whole, originate from several common properties and performance requirements as regards their functional utilisation[5]. Detailed review and analysis of the two sectors including a brief presentation of the profile and market orientations of the two industries is provided with Annex 9.2.

In order to test hypothesis 1 four companies are reviewed. The consumer ceramics sector[6] is represented by C3 and C4. C3 is a large consumer ceramics producer (with strong foreign ownership participation) specialising in the production of tiles for construction or decorative applications. C4 is a large production unit of sanitary ware operating as the Greek manufacturing and distribution branch (subsidiary company) of a multinational giant specialised in the production of products and materials for construction and building applications. The refractory sector is represented by C5 and C6. C5 is a large refractories producer established in the early 1970s with assistance provided by a German refractories company and since then it operates as an "equal partner" (not as a subsidiary) of the German company. C6 was established in the early 1980s based on entirely Greek funds and efforts. All four companies export 20-40% of their annual output to quality and performance demanding markets and they intent to increase this percentage within the next years. C5 intents to enter new markets dominated by advanced ceramics applications.

<u>Technology And Materials Strategies</u>

For all the reviewed companies the term 'business and technology strategies' is almost synonymous to the term 'materials strategies' while processing/production technologies are in effect S&P technologies[7]. Therefore, all the reviewed companies perceive materials competencies, and hence materials strategies and R&D activities, as crucial determinants of their business competitiveness.

With respect to production technologies (i.e. production lines and manufacturing equipment), all four companies depend upon internationally acquired know-how

[5] Such as mechanical strength, surface hardness and abrasion resistance, colour resistance, surface finish, resistance to chemical attack, fracture toughness, weight reduction etc.

[6] A detailed profile of the consumer ceramics sector is provided by Giannarou (1992), *'The Greek Sanitary Ware and Tile Industry'*. MBA Thesis, City University Business School, London.

[7] The consumer ceramics producers gave a broader meaning to the argument because they are involved in a broader spectrum of products and hence processes and manufacturing technologies.

which is integrated to the capabilities and needs of each company through specialised internal mechanisms. Due to the special ownership status of C3, C4 and C5, technology transfer does not involve payment of royalties but exchange of technological information, equipment and know-how[8].

On the contrary, materials and product know-how has been developed internally (in-house), and, apart from the special case of C4, materials innovations are mainly the result of internally organised R&D efforts[9]. Each company has a small[10] MSE dedicated R&D laboratory located at, or very close to its production site.

C5 and C6 (the refractory sector) focus their technological and R&D activities almost exclusively on refractories and other ceramics (tiles) for high temperature applications. Currently, there are no diversification efforts into functional ceramics or into ceramics for non-high temperature applications. Only C5 provides extensive emphasis to pre-competitive research by allocating approximately 30% of its resources to the development and production of advanced refractories and other related products. C6 clearly focuses on applied and competitive materials research and improving incremental materials rather than developing new materials.

C3 and C4 (consumer ceramics) follow more aggressive business policies by pursuing a simultaneous materials-based backward and forward vertical integration and diversification of their activities by entering and controlling raw materials production and supply and a supportive network of products and services relative to their mainstream products[11]. Both companies have a small MSE dedicated R&D group[12] located at, or very close to their major production sites.

With respect to materials related research, C3 provides emphasis on the design and the economic production of new products (e.g. the production and commercialisation of holographic tiles) based on improved or advanced S&P techniques. C3 has pioneered the development of real scale pilot production lines dedicated to real production conditions testing new products or R&D results. The R&D portfolio of C4 directly

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[8]C4, being a subsidiary of a multinational group, has a much larger pool of know-how from which the company can draw knowledge and technology. As C4 put it, " .. *only in EU countries the group has 15 large production factories controlled by sister companies. It is the policy of the parent company to encourage the uninhibited exchange of information and know-how between the subsidiaries in terms of both materials and manufacturing know-how*".

[9] As C6 pointed out, "... *when it comes to materials per se, internally generated know-how is all that counts. Licence agreements are insufficient to provide the essential details and the critical knowledge.*"

[10] Which includes 3-4 full time researchers.

[11] C3 for example, is active in the production and distribution of adhesives and glues for tiles and other relative materials. C4 is providing increasing emphasis to the utilisation of polymer materials and has initiated efforts for the development of functional ceramics (e.g. catalysts) for transport and industrial applications.

[12] Including research teams of 7-8 full time researchers.

follows the strategic concepts and directions provided by the parent company. As C4 explained:

> "... in order to be competitive our industry needs an optimum combination of technological competencies and cheap production and distribution of products. Hence, the parent company has established many subsidiaries to optimise the geographic production and distribution of its products. Thus, it is the core strategy of the parent company **to retain in the key technological competencies** centrally (and gradually, when conditions permit, diffusing them to selected subsidiaries). **New and advanced materials know-how is regarded as one of the most important core competencies**; hence the parent company has committed itself to strategic materials research while the subsidiaries are committed to near market research and in research supporting the parent company's research."

Thus, the R&D portfolio of C4 provides particular emphasis on the improvement of the efficiency of production and S&P technologies (including materials research which improves the performance of machinery and instrumentation) and on materials substitution in order to increase the competitiveness of existing products, not on new and advanced materials research. C4, also dedicates approximately 15% of its R&D resources in new materials research including research on *advanced functional ceramics* such as ceramic-based catalysts for energy and pollution control applications which the company perceives as a "... *low risk adventure*".

In addition, all four companies provide emphasis on all four elements of the materials tetrahedron giving particular emphasis to the element of S&P. The R&D and production research units of each company receive extensive support and feed-back from many other related units such as information gathering and evaluation units, technology transfer units, etc. In addition, each company receives extensive R&D support from external partners, that is outsourcing of R&D activities non-crucial for the competitiveness of the company. These activities are usually supported by R&D collaborations with Greek and universities abroad and technological / research organisations within the framework of national and international R&D collaborative schemes.

<u>Management Practices and Core Competencies</u>

Over the last 10 years, both subsectors have benefited from the adaptation and implementation of Kaizen and SE practices including the introduction of automation, team-work concepts, product and process optimisation cycles, and SE approaches by achieving constant improvements in product quality and production efficiency including significant production cost reductions[13]. Simultaneous Engineering practices

[13] For example, through the introduction of Kaizen practices and management perceptions, C4 managed to achieve a 35-40% production cost reduction within five years (1990-1995) (CERECO 1996).

are usually employed during the design and/or optimisation of the manufacturing outline or the R&D portfolio of each company. As in the case of C1 and C2, SE practices could also be employed during the design of new product and materials development including direct technological involvement of final materials users ("Open SE" – see chapter 4). But as all four companies pointed out, the most commercially important customers - the metallurgical sector and the construction sector – are not effectively involved in such commitments because they provide emphasis on cost considerations, "the cheaper, the better", rather than technological performance.

With respect to *core competencies*, the reviewed refractories companies believe that the concept of core competencies is clearly related to each company's MSE capabilities and to its ability to optimally couple them with their production capabilities. The reviewed consumer ceramics companies define their core competencies as a combination of materials and processes know-how and commercial competencies such as low prices for high quality products (C3, C4) and elaborate customer services (C3) (for details see Annex 9.2).

Financing of R&D and Technological Innovation

All four companies have similar views for technology and laboratory infrastructure investments (they are perceived as a long-term strategic investment) but due to capital (C3, C5, C6) or externally defined operational limitations (C4) R&D expenditures are dominated by the "net present value " rule (C5, C4) or are seen as an overhead with the annual allocated budget as a fraction of annual profits -something similar to second generation R&D (C3, C6). Moreover, the sources of funding for R&D activities vary considerably among the reviewed companies. C3, and C5 finance their R&D activities almost exclusively out of their own resources and occasionally they supplement their R&D budgets through participation in the NCRDP. C4 follows the same strategy and occasionally receives subsidies from the parent company, while in the case of C6 which is the weakest of the reviewed companies, approximately 40% of the annual R&D expenditures are covered by external resources – that is participation in R&D collaborative schemes. Hence C6's R&D portfolio is strongly dependent on the approval of R&D collaborative proposals in which the company is a participant[14].

[14] Note that MU2 and MU5 has similar limitations and they have adopted similar approaches.

9.1.3: Ceramic producers: Common topics and practices

The views and the practices followed by both the cement sector and the consumer ceramics and refractories sectors converged in a wide range of issues. The following paragraphs summarise the most important of them. A detailed sector analysis of these concepts including implementation details is provided with Annex 9.1 (cement sector) and Annex 9.2 (consumer ceramics and refractories sector).

Supportive technological competencies

All the reviewed ceramic producers (C1-6) support their R&D and their operational activities with institutionalised internal mechanisms which include:

- Organised and elaborate technology intelligence gathering mechanisms (apart from C6). In the case of C2 and C4 that takes the form of information exchange within the international network of sister companies. They have also established constant communication links between their information gathering/evaluation units and their R&D divisions. Such feed-back is a key element in achieving a science push/market pull combination.
- Customer needs evaluation mechanisms supported by extensive and constantly updated customer data banks and in co-operation with the information gathering units.
- Regular investments and updating of machinery and instrumentation which are designed simultaneously with the business and technology strategies of each company and perceived as long-term strategic investments upon which the long-term competitiveness of the company depends.
- Internal simulation and modelling skills: C5 and C4 apply these skills in "everything", C6 employs simulation and modelling only for manufacturing improvements and not in R&D activities and C3 is currently outsourcing its needs but it is in the stage of developing internal skills. C2 has internal teams dedicated to the *simulation and modelling* of processes, products, materials and distribution / supply systems. C1 has just started to develop these skills in connection with the company's participation in R&D collaborative schemes.
- All companies provide particular emphasis on long-term employment stability and on smooth transition of knowledge and experience between incoming and retiring human resources. In addition all companies (especially the large ones) have developed internal education and training schemes including exchange of students, international seminars and continuous education programmes.

Technological Interactions, Co-Operations and Alliances

Both the cement and the consumer ceramics and refractories sectors underlined that the formation of links with universities and research/technological institutions and the formation of technological co-operation is a basic element of their technology strategy. All the reviewed companies believe that learning-by-interacting creates strong industrial and human networks and multi-dimensional R&D and technological clusters with complementary powers. Technological collaborations are perceived as the key for successful technology transfers, introduction of new materials into demanding markets, materials or products development or improvement, processing improvements, manufacturing optimisation, training and education of human resources, etc. Hence, as C2 put it "... *the company does not only try to enter technological collaborations tailored to our technological needs but to continuously optimise them.*"

In this context all the reviewed companies have developed strong commercial and occasionally technologically complementary ties with their machinery and materials suppliers (e.g. collaborations among the cement and the refractories industry) but they declined the request to provide further detailed information on the issue. In addition, C2 regularly enters into "collaborations" with domestic or international SMEs which it then uses as “market probes” for niche markets and applications or eventually acquires if they have substantial know-how to offer (see also analysis in Annex 9.1).

Nevertheless, complementary collaborations on the basis of the materials user - producer relationship described in the Alcoa-Audi case study are rare because the final users of the sectors’ products are unable or unwilling to respond to the sectors’ technological standards[15]. **This lack of sufficient technological (and market) pull from the primary customers of the consumer ceramics and refractories sector is unanimously regarded as the main obstacle for expanding the R&D activities of the two sectors** and developing en-masse advanced refractories and advanced consumer ceramics for industrial and every day applications. C5, C2 and C1 are trying to motivate and increase the technological awareness (not just the commercial) of the final users of their products (construction industry), and of the basic metals producers industry (C5).

[15] The construction sector perceives the products of the cement and consumer ceramics sectors as commodities and thus gives priority to commercial and cost considerations. The basic metals sector (intensive final user of refractories) also provide more emphasis to cost rather than performance and appears to be technologically isolated from other sectors (see also below). Only the consumer ceramics and the cement sector has developed complementary technological collaborations with their refractories suppliers.

Interactions with universities and research / technological institutions

The cement and the consumer ceramics sectors have developed the strongest links with both universities and research / technological institutions.

With respect to industry-university or research institution technological collaborations, the collaboration takes the form of either common participation in the NCRDP and international R&D programmes or *the form of R&D outsourcing*, that is the provision of R&D services on the basis of contracts. Similar conditions apply in the case of industry –research/technological institutions technological collaborations. Over the years some companies (e.g. C1, C2, C4, C5) have developed some unofficial but strong links with specific research teams which are regularly employed by them. The co-operation takes either the form of requesting research on contract or more frequently the participation in a common national R&D collaborative programme where these companies are the industrial users.

Technological collaborations usually focus on applied and competitive materials research. The average project duration is 2-3 years (all sectors). Industry –university collaborations focus more on materials characterisation, properties and performance evaluation while industry-technological institutions collaborations include all four elements of the materials tetrahedron and provide emphasis on the element of S&P (see also the role of universities and technological institutions in chapter 8). These arrangements reflect the needs and the materials interests and R&D portfolio of the reviewed companies (incremental improvements in existing structural materials and S&P technologies, simulation and modelling applications), while, clearly, they cannot support materials pre-competitive research, advanced materials or S&P research and new materials research.

In addition, the ceramic producer sectors including cement industries have contributed to the establishment of the Greek Ceramic Association whose mission (among others) is the exchange of information and the promotion of collaborations between the companies of the sector and took the lead in the establishment of RI1, the only dedicated ceramics research and technological institution in Greece (reviewed in chapter 8). Since RI1's establishment in 1986, cement and ceramic producers are among the basic supporters of RI1, they have a long record of common research projects and common participation in national and international R&D collaborative schemes and they constantly persist in the expansion of RI1's activities and services.

9.1.4: Conclusions On The Ceramics Producers Industry

According to the preceding information the cement, refractories and consumer ceramics sectors (ceramic producers in brief) **verify** the materials producers hypothesis (**Hypothesis H9.1**) because the companies of the sector perceive materials strategies and materials capabilities as a fundamental competitive advantage and they have developed complex and sophisticated materials strategies tailored to the needs or in support of their technology and business strategies. In more detail:

- All the reviewed companies and sub-sectors include in their R&D activities all four elements of the materials tetrahedron and provide particular emphasis on the element of S&P and the simultaneous development / design of R&D activities tailored to their present or expected S&P and production capabilities.
- They tailor or support their operational strategies on their current or in the process of being acquired or developed materials capabilities.
- They have developed small but substantial MSE oriented R&D activities tailored to their business needs and operational capabilities.
- They have adopted a third generation style of R&D activities, even though the financial limitations of many companies and the clearly short to medium term (maximum 4 years) of the their projects duration inhibits the effectiveness and limits the potential benefits of third generation R&D.
- They have adopted and incorporated Kaizen management practices in both their production and R&D activities.
- They have identified the issues of core competencies and they zealously protect and capitalise on them.
- They have developed internal institutional arrangements (e.g. human resources policies, simulation and modelling skills etc.) in support of their materials, technology and operational activities.
- They interact with their environment and they form technological collaborations and supplement learning by doing with learning by interacting. They are committed to building industrial networks and information discussion mechanisms.
- They have identified common technological needs and the three reviewed sub-sectors are operating as loose but clearly shaped industrial clusters.

- They perceive investments in technological infrastructure as a strategic investment and they have adopted strategic internal controls to justify their investment decisions.

Hence, ceramic producers operate in agreement with the international codes of practice as described in chapters 2-6 and **verify** the working hypothesis of chapter 9. Moreover, the ceramic producing sectors have a profitable turn-over over the last 5 years. Thus, in their case, the combination of the two facts **verifies** hypothesis H9.4 and the findings of the NRC (1989) study on advanced materials technologies.

It is notable however, that the Greek ceramic producers are reluctant to diversify into functional ceramics for electronics, environmental or energy applications. The only area which has been unanimously identified and systematically pursued is the field of ceramic coatings and advanced surface treatments. Otherwise, when advanced materials diversification efforts are noted, they almost exclusively involve advanced structural materials and their applications. The industry has recognised that its main strengths are exactly in this field and appears reluctant to diversify in high risk "adventures".

In view of the above, it is estimated that all the reviewed ceramic sectors have the potential to move into the development and commercialisation of structural ceramics for energy applications (e.g. energy conservation - insulation) and in ceramics for luxury products as C3 is already doing. A serious obstacle is the relative reluctance of the final users of these products (e.g. the energy production sector and the construction industry) to adopt and widely utilise them.

9.2: Materials Producers: Metals - Ferrous and Non-Ferrous Metals Producers

The same hypothesis (hypothesis H9.1 for materials producers) tested in the case of the ceramic sectors applies in the ferrous and non-ferrous metals producers. It is presumed that both sectors are able to respond to the materials revolution challenge by developing and efficiently supporting complex materials strategies as an integral part of their technology and business strategies.

The basic metals sector includes two sub-sectors: ferrous metals (e.g. production and utilisation of steel and production of nickel) and non-ferrous metals (e.g. production and utilisation of alumina and aluminium and utilisation of copper).

In terms of annual production output of basic metals and finished metal products both sub-sectors are dominated by a handful of large corporations employing more than a

500 workers (ICAP 1994). The following analysis focuses only on large (more than 500 workers[16]) companies which dominate both the production and utilisation of metals. Four ferrous and two non-ferrous metals companies are analysed.

The ferrous metals sample includes M1[17], the largest capacity production unit in Greece (in 1993/94) operating under foreign supervision and control, M5St, a smaller unit operating since the early 1990s as a member of M5 (a large industrial conglomerate reviewed in detail in the non-ferrous metals sector) and M4 the largest casting company in Greece producing cast iron products for technologically demanding applications[18]. Finally the ferrous metals sample includes M2, a profitable public enterprise, producing and exporting 100% of the annual Greek production of nickel and ferronickel. The non-ferrous metals research sample analyses the materials and business strategies of M3, the only aluminium producer in Greece and M5, a huge industrial conglomerate[19] of intermediate or semi-finished aluminium and copper products or components which find their way in low-to-medium technology commodity applications (with the exception of a limited range of products for electric/electronic applications).

Given that the materials and technology strategies of the reviewed companies vary considerably, both the ferrous and the non-ferrous metals sector are analysed on the basis of six case studies corresponding to each reviewed company. The ferrous metals case studies are reviewed in detail in **Annex 9.3** and the non-ferrous metals case studies are reviewed in detail in **Annex 9.4**. The following section summarises only the key points of each sub-sector.

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[16] With the exception of M4 which is a specialised company.

[17] M1 was the only production unit in Greece able to produce pure iron smelting iron ores in blast furnaces. Since 1981 however, M1 terminated their operation on the basis of cost considerations.

[18] It should be mentioned that the Greek metals sector (the ferrous metals companies in particular) is very secretive and they do not disclose any information on their activities to researchers (Mantzavinos 1990, Industrial Review, Special Issue No.11, March 1994). Since 1987, the present thesis is the first academic study able to present an analysis mainly based upon *primary data* obtained during face-to-face interviews with leading officials of the reviewed companies, and use secondary data (published information) only as supporting material.

[19] Including two large aluminium products units, two large copper products units, one cables and wires production unit, one steel producer (M5St), one welding rods producer, a tiles producer, a metallic construction materials producer and many other smaller companies producing non-ferrous high-value added products.

9.2.1: Ferrous Metals - Technological considerations and materials activities

The case of M1. M1 produces steel by recycling scrap and by employing internationally acquired, mature steel production technologies (mini mills and electric arcs) which the company has "... *simply learnt to use..*". Despite the gradual intensification of competition, M1 appears to be "technologically compromised" as it responds to rising competition by solemnly attempting to constantly compress production costs and increase production efficiencies (M1 October 1996). The company has neither invested in the development of R&D strengths including reverse engineering capabilities nor developed R&D activities[20]. Any materials related activities are connected either to properties or performance certification of standardised products or to efforts to improve the S&P of standardised products without compromising their standard performance.

The case of M5St. Until the early 1990s, the case of M5St was very similar to the case of M1. As in the M1's case, the technology strategy of the company provided priority to cost reductions and production efficiency improvements of steel commodities. M5St had neither R&D capabilities (only quality control facilities) nor reverse engineering mechanisms.

Since 1991, however, M5St was acquired by the M5 conglomerate (reviewed in detail in Annex 9.4). The new leadership introduced the concept of gradually transforming M5St from a commodity producer, into an intelligent materials producer by capitalising on the technological and commercial opportunities offered by advanced materials and MSE related technologies. The concept of cost reduction and production efficiency improvement has been preserved but it has been coupled with the simultaneous introduction of incremental product improvements and the introduction of new products (internationally established but new in Greece – a concept also applied by C1) such as advanced structural steels with significantly improved properties[21].

In order to support these changes M5 made significant changes in the internal structure and organisation of M5St such as the introduction of Kaizen management principles, the development of internal supportive competencies – e.g. simulation and

[20] Even though it has well equipped laboratories whose activities are exhausted on quality controls and certifications of products or processes and the resolution of day to day problems arising during the operation of the company.

[21] A very good example is provided by the case of S500S or St4, an advanced structural steel for large scale constructions. This structural steel has superior *welding* properties and offers significant technological and financial advantages in the construction of heavy structures such as building skeletons and bridges. This steel was first developed and commercialised in Europe, but M5St is the first and so far unique Balkan steel producer to introduce it in Greece and in the Balkan markets.

modelling departments - the strengthening of M5St's R&D capabilities and the increase of the level and the quality of technological interactions of M5St with its environment and with other companies.

The case study of M4. Given that for M4 the term materials strategies is almost synonymous with the term technology and business strategies, M4 has built its business orientations and operational capabilities around its materials-technological capabilities. The company has made the strategic choice to gradually enter the production of specialised advanced casting products (including aluminium castings) by capitalising on investments in emerging casting technologies and its in-house expertise[22]. Focus is provided on the ability of the company to implement advanced but existing materials in order to produce high-added value products. Only occasionally the company takes the initiative to experiment with new materials such as experimental mixtures of zinc and aluminium. In order to support these strategies the company has a fully equipped, MSE dedicated R&D laboratory located "next door" to the company's production plant. The lab is able to carry out complex R&D tasks but the average project duration is no longer than 2 or 3 years. M4 does not have any pre-competitive research activities.

Nickel producers: the case of M2. M2 is nor only a technology and materials intelligent user but also a technology developer. Since 1967, the company produces ferronickel by using unique in the world technologies (pyrometalurgical methods developed by the company) which enable the exploitation of very poor nickel ores (1.1-1.5% Ni). Given that the company operates with very low profit margins and high production costs, that the mainstream products of the company (nickel and ferronickel) cannot be further improved or altered, and, that the ferronickel industry is subjected to constantly rising EU environmental regulations, the entire operational, technology and materials strategy of M2 is directly related to these restrictions and its defined by three parallel streams of action:

- The simultaneous improvement of production efficiency and production cost compression (as M1 and M5St),
- Diversification of activities / generation of new activities by exploiting the technological and commercial opportunities of the nickel processing by-products,
- Entering new markets and creating new products as spin-off results of the two previous activities.

[22] The company commenced operations based on internationally acquired technologies (Hungarian Know-how). But since then, the company has completely absorbed this technology and has developed its own know-how and techniques.

The R&D portfolio of the company is tailored to support these three streams of action (see Annex 9.3). M2 follows a de-centralised R&D organisational approach where each department has its own R&D capabilities. In administration terms however, the company has a small division dedicated to the monitoring, supervision and co-ordination of the entire R&D activities of the company. There is also a large MSE dedicated laboratory with the mission to support all the peripheral activities of the company and provide feed-back and services on common issues and needs.

9.2.2: Non-Ferrous Metals - Technological considerations and materials activities

The Case Study Of M3. M3 is a subsidiary company operating under the direct supervision of its parent company, a large EU Aluminium and Alumina producer. Hence, the operational, technology and materials strategies of M3 are largely defined by the parent company. As such, with respect to technology and materials policy issues, M3 operates under a framework very similar to that of C4 (see the consumer ceramics section). M3 explains:

> "M3 is not supposed to engage in emerging technologies or advanced materials research nor to alter the properties, quality or performance of our final **mainstream** products. These are the mission of the parental company. We have the duty however, to engaged in R&D which reduces production costs and / or increases production efficiency without compromising our final mainstream products quality. We also have the choice to be engaged in R&D targeting secondary products or R&D targeting supporting technologies or secondary areas (e.g. recycling of by-products, simulation and modelling skills) from which the entire network of sister companies can benefit[23]. "

Under these arrangements, the company has a centrally located R&D laboratory almost exclusively dedicated to S&P improvement and production issues and very recently to provide solutions on recycling and environmental problems. An additional stream of R&D involves research on supportive technologies such as the application of automation and simulation and modelling during all S&P stages.

The case study of M5. As the M5 officials explained, all the mainstream products of the group target are the output of internationally mature (base) technologies where the pace of technological change is slow, competition is high and the profit margins are low. The combination of these inflexibilites combined with the fact that M5 does not have the required size to be a global technology leader, inhibit the group from engaging in large scale R&D targeting entirely new manufacturing technologies or

[23] Note the striking similarity with the case of C4.

new materials. In addition, M5 has taken the deliberate decision, not to enter emerging aluminium markets (e.g. transport industry) until the beginning of the next century.

As such, with respect to mainstream products, the technology strategy of M5 is the *intelligent reclamation and implementation of mature technologies* which enables the group to be on the leading edge of the available but established technologies and products. M5 follows more aggressive strategies (supported by proportional R&D activities) in niche markets and specialised products (e.g. specialised welding rods tailored to the superior welding properties of St4 produced by M5St or very thin aluminium foils and membranes). M5 believes that these activities will eventually become the diversification vehicle of the group to enter high technology markets such as electronics and telecommunications.

The group has a decentralised R&D approach where each production unit has developed and is responsible for its own R&D portfolio on the basis of the above described targets. The R&D divisions trace their origins to the quality control divisions of each member of the group. These divisions include a hard core of researchers and a flexible number of additional production or services scientists and engineers which contracts or expands on the basis of the needs of each individual project. The R&D activities of the group are tailored to support the technology and business choices of the group. The R&D portfolio includes:

- R&D targeting S&P and production including reduction of processing cost and increase in production efficiency. On this point M5 has a very similar strategy to M2 and M3 and actively supports research on materials which will indirectly but ultimately improve the operational and production capabilities of the group.
- Small incremental improvements of structural materials (the mainstream products of the company) when a long-term contract for major quantities is secured.
- R&D targeting problems originating from customers' requests.
- R&D focused on materials for specialised or niche applications (structural materials and a few cases of structural/functional materials). This stream of action frequently involves pre-competitive research.
- The tackling of every day production or services problems.

9.2.3: Basic metals producers: Common topics and practices

Aside the technology and materials strategy differences, the two basic metals sectors share many common materials strategy characteristics and some notable weaknesses. The following paragraphs summarise the most important of them. A detailed case study analysis of these issues including company/sector implementation details is provided with Annex 9.3 – ferrous metals and Annex 9.4 – non-ferrous metals.

- With respect to the four elements of the materials tetrahedron, no perception problems were detected. Moreover, all the reviewed companies, which have developed materials R&D activities, provide particular emphasis on the element of S&P but only M2 and M5 has provided some examples where this is connected to the simultaneous development or improved materials targeting final products. All the other companies try to improve S&P (in terms of efficiency) while keeping the properties and performance of their mainstream products as a point of reference which must not be compromised or altered.
- With the exception of M1 and M5St all the other reviewed companies have developed small but substantial MSE oriented R&D activities tailored to their operational needs. But the primary aim of the R&D activities of each company is to support the S&P improvement routine. There is no materials (or other technologies) pre-competitive research and there is no research targeting new materials to be used as mainstream products. The support of diversification strategies or rejuvenation strategies through the development of new advanced products comes as a second supplementary priority and with respect to secondary products (e.g. M4 – aluminium castings using experimental alloys, M2 - production of construction ceramics as by-products of its nickel production operations, and, M5 – production of optical cables and aluminium membranes).
- Apart from M1, all the other companies have adopted a third generation style of R&D activities even though the clearly short to medium term projects duration, and the over-conservative R&D portfolio inhibits the effectiveness and limits the potential benefits.
- Apart from M1 all the other companies perceive investments in technological infrastructure as a strategic investment and they have adopted strategic internal controls to justify their investment decisions. However, only M3 and M5 perceive investments in R&D as a strategic investment; all the others (including M2) regulate internal R&D investments using the "net present value" rule. In addition, M5 and M3 finance their R&D activities almost exclusively from their own

resources. M4 and M2 use their own resources and funds obtained from participation in the NCRDP.

- All the companies of the sector (including M1) have adopted (or they are en-route to adopt) continuous improvement, TQC, Just-In-Time and other Kaizen practices which have been incorporated primarily in their production activities (as a direct outcome of the need to optimise production efficiency and constantly reduce cost) and recently to their R&D activities. SE engineering practices however, are less common among the companies of the sector because, as M5 pointed out, the companies of the sector are components providers, not integrated manufacturers such as a car manufacturer. Hence SE practices are employed primarily during collaborations with other companies - especially when large machinery suppliers are involved (M3, M2, M5) - in order to optimise the collaboration and its results.

- All the reviewed companies have identified the issues of core competencies which they vigorously support and protect. The views of what each company perceives as its basic core competency varied considerably (for details see individual case studies in Annex 9.3 and Annex 9.4). The most common areas were:
  - In-house know-how on materials and processing technologies (M2, M4),
  - Ability to understand and apply materials rejuvenating theoretically exhausted technologies (M2, M5),
  - The adaptation and the successful employment of continuous improvement and other Kaizen principles in S&P and production (M1, M4),
  - Production and manufacturing capabilities[24] (M5),
  - The combination of good quality – low prices products (M4, M3),
  - Customer services and follow-ups (M5, M4).

  It is notable that only M2 and M4 and partially M5 perceive materials - related capabilities as a corporate core competency. This comes as a major surprise from a materials producing sector and demonstrates that the sector is clearly oriented to the production of conventional and occasional incremental materials and not products based on advanced materials and processes.

- All the reviewed companies have installed institutional and organisational arrangements (supportive core competencies) mainly in support of their operational activities and not that much in support of their materials and technology strategies. Emphasis is provided to simulation and modelling applications applied both in

[24] M5 has the capability to adjust the production lines of the group in order to be able to respond to many major standard systems such as DIN (Germany - Central Europe), JIS (Japan), BS (Britain) and ASTM (International - USA).

production and in S&P improvement efforts. M3, M5 and M2 have particularly invested in this area.

- The basic metals companies have developed strong commercial ties and occasionally complementary technological collaborations (M2, M3, M5 – some members of the group) only with their machinery suppliers or with international companies which develop technological know-how crucial for the operation of the company. The case of M3 in particular (and the case of M2 and M5 to a lesser extent) resembles the complementary technological alliance between Alcoa and Audi. M3 (and occasionally M2 and M5) acts as the final materials user and enters long-term technological collaborations with machinery and materials suppliers in order to assist them to improve or develop advanced materials which improve machinery performance and hence improve production efficiency of the company. M3, M2, and M5 however, never contribute to the production of these materials. Their contribution goes as far as the development and testing stages. In addition, the sector has developed internal tight commercial bonds, but not industrial networks or technologically complementary clusters. Some of these bonds tend to be transformed into technologically complementary collaborations (e.g. M3 as the materials producer and M5 and the materials user). The interviewed official declined the request to provide further information.
- Neither the ferrous nor the non-ferrous metals producers have developed technology-based collaborations or links with the Greek construction industry and the Greek defence industry (final users or potential final users of their products). In addition, the basic metals sector has taken no initiative to increase the technological awareness of the construction sector or establish technological links with the construction or the defence industry. This approach is the antipode of the approach adopted by the cement and commodity ceramics sectors.
- Major segments of the basic metals sector (M1, M5st, M5) tend to be isolated or keep their distances from domestic research/technological organisations, Greek universities and from participation in R&D collaborative schemes. In addition, the interactions of M3 with universities and research institutions is only "*...occasional and take the form of R&D outsourcing for non-sensitive R&D projects*[25]". A possible explanation is the distrust of the industry for "outsiders" or the "*...incompatibility of scopes*" as M5 and M3 put it.
- On the other hand, M2 and M4 have developed closed ties with academic and research/technological institutions and regularly participate in both national and international R&D collaborations. M2 in particular, pointed out that it is this

[25] E.g. simulation and modelling applications of the production operations of the company.

collaborations that have provided the basis for many of the technological competencies of the company. Clearly, the case studies of M2 and M4 indicate that there is common ground between research organisations and the Greek basic metals sector. They opportunities just need to be explored.

- In addition, some of the reviewed companies (e.g. M3, M2, M5) have actively participated in the establishment of RI2, the only Greek research and technological institution dedicated to metals and their technologies[26]. Since its establishment in 1986, the basic metals producers are among the basic supporters of RI2. However, the industry perceives the institute mainly as *a technological services provider rather than a R&D partner*. Thus, the record of common R&D projects or common participation in collaborative R&D schemes is low and RI2, originally designed to technologically assist the sector, has limited technological influence over the very conservative or technologically indifferent basic metals sector.

9.2.4: Conclusions on the Metals Producers industry

According to the preceding information there are notable technology and materials strategy variations within the basic metals sector.

The *steel industry* is either *technologically* compromised or in the process of developing relatively simple materials strategies as a response to rising international competition. Prior to the beginning of the 1990s and with the exception of M2, all steel producers were in decline caused mainly by the inflexible determination of their leaderships to persist with mature and "exhausted" products and technologies. During that period the Greek steel producers had not identified the utilisation of R&D results as a tool to maintain competitiveness or as an entry barrier able to protect their markets. As such, they did not develop advanced materials strategies on the basis of the international experience (even though they had the necessary corporate structures and internal mechanisms to support them) and they have accumulated significant losses over the last 10 years.

This situation has been reversed since the beginning of the 1990s. Under the impact of new management perceptions inspired by international experience, all the reviewed ferrous metals producers, (with the exception of M1), are committed to the gradual development of sophisticated materials strategies tailored to their increasingly aggressive business objectives. Capitalisation on new technologies and R&D results is increasingly emerging as a priority. Even though the materials strategies of the

[26] Reviewed in chapter 8.

reviewed companies are still fragile,[27] the sector has started to turn profitable results (apart from M1[28]) and it is considered to be on its way to develop and efficiently support complex and sophisticated materials strategies over long periods of time.

On the contrary, the *non-ferrous metals sector* has always perceived materials strategies and materials capabilities as a fundamental source of competitive advantage and has developed mature technology strategies as a response to technological and market competition.

Nevertheless, the materials strategies pursued by reviewed companies are very conservative (even technologically compromised). The companies of the sector, under the argument that their mainstream products are commodities, are clearly committed to the improvement of incremental and conventional materials and to the intelligent exploitation of advanced but well-established technologies and S&P procedures. Hence, they have structured their materials strategies on the basis of improving S&P technologies, intelligently exploiting mature technologies and only critically improving incremental materials / mainstream products. They do not attempt to diversify into functional materials and, contrary to the cement or consumer ceramics sector, they are not committed to pre-competitive materials research and they do not even target the development of new structural materials.

According to the findings of chapters 2 and 3, this is the most conservative approach, it is recommended only for "beginners" such as M5St after its acquisition from M5, but it is a very risky approach when it is not supported by a parallel stream of activities targeting the development of new materials and S&P technologies which provide new business and market opportunities. Indeed, the commodity materials argument, invariably used by all the reviewed companies is very fragile. British Steel has achieved an impressive performance in the global heavy construction markets with SlimDek, a light-weight advanced structural steel[29]. SlimDek, a mainstream new structural material, is the outcome of simultaneous S&P and materials R&D and the product of a long-term co-operation between British Steel and many universities and research organisations. SlimDek is both a commodity and an advanced material and

[27] Notable is the aloofness of M5St from research organisations, the poor technological links of the sector with intensive materials users such as the construction industry, the size limitations of M4 and the high project dependence of M2.

[28] M1 is a puzzling case. The company appears to be "technologically resigned" even though it has the operational capabilities to develop, efficiently support and capitalise on advanced materials strategies. However, the leadership of M1 has chosen to follow a technology strategy which can only delay the final decline of the company. It is not clear if this decision is dictated by the foreign ownership of the company and reflects a part of a restructuring plan of the production facilities of the holding company all over Europe. If that is the case, then there is no puzzle.

[29] Presented in chapter 3, section 3...., Box 3.... .

provides an excellent example of the nature of challenge the Greek metals producers are about to face.

Nevertheless, even though the materials strategies of the reviewed companies have some notable weaknesses the non-ferrous metals sector and major segments of the ferrous metals sector are considered to be able to sustain and efficiently support more complex and sophisticated materials strategies in the near future because they have developed the internal organisational structures and employ management practices necessary for their support and implementation.

In view of the above, the "working" hypothesis H9.1 (materials producers) has been **fully verified only** in the case of non-ferrous metals producers. It has been **partially and marginally verified** in the case of ferrous metals producers.

In addition, the patent emerging from the basic metals sector is identical with the patent identified in the NRC (1989) study on advanced materials technologies. In Greece, only individual companies (ferrous metals) and the non-ferrous sub-sector have a consistently profitable record. These are the companies with the most audacious and complete materials strategies. On the contrary two companies (M1 and M5St before 1994) with the weakest materials strategies, constantly accumulate losses. The USA steel industry underwent a similar experience during the early and middle 1980s and also faced severe competitiveness losses. The combination of the these facts **verifies** hypothesis H9.4 and the findings of the NRC (1989) study on advanced materials technologies.

Finally, the analysis of the basic metals sector provided two additional findings.

The relative remoteness of the sector from research institutions and the lack of commitment in materials pre-competitive research have a direct negative effect on the related domestic research organisations. Until 1986 for example, the Metallurgical department of Athens University had a clear mission: research activities and training of scientists and engineers in advanced metallurgical technologies in order to support the domestic basic metals sector. The lack of interest of the sector forced the department to diversify its interests into other areas of higher industrial demand such as environmental and recycling technologies which have attracted some attention from the basic metals industry. In addition, given that RI2 has very few demanding technology users who are willing to seek its services, it is rapidly declining from a technological institute into a services provision organisation[30].

[30] Note that while RI1 (ceramics) identified as its basic core competency the ability to deliver integrated materials and S&P solutions to industrial problems, RI2 identified as its core competency its uniqueness in Greece and its low-cost, high-quality services.

The case of M2 demonstrates that *Greek public enterprises can operate successfully* without any substantial governmental support if they capitalise on R&D results and develop solid materials and technology strategies as a part of the needs of their operational strategies and business objectives.

9.3: Materials Final Users: The Defence and the Construction Industry

Two intensive materials using sectors are analysed: the defence sector which is primarily a major advanced structural metals using sector, and the construction sector, an intensive incremental and advanced ceramics and metals sector. The **defence sector** is analysed on the basis of **hypothesis H9.2a** and the construction sector on the basis of **hypothesis H9.2b** (see introduction of chapter 9). *Variations* of the findings between the sectors are expected.

9.3.1: The Defence Sector

The defence industry is analysed on the basis of testing hypothesis H9.2a. The industry include six major production units. Five of them are public enterprises and four of the operate under the direct control of the Greek MOD. The sample includes the views of five units. Four of them are public enterprises and three of them (MU2, MU3, MU4) operate under the direct supervision of the Greek MOD. Detailed analysis of the sector including information on its character and operational environment is provided with **Annex 9.5**.

<u>Key Characteristics of the Industry</u>

- Greece dedicates approximately 4-5% of its annual GNP for defence expenditures. The primary mission of the Greek defence industry is to support the operational capabilities of the Greek army and substitute imports of military equipment, weaponry and ammunition with high-quality domestic products.
- The Greek State totally dominates the defence sector both as the primary final (and in many cases the only) customer of the output of the sector and as the final decision maker for the four major production units of the sector directly controlled by the Greek MOD.

Technological and R&D considerations

** The technology strategy of MU1 to MU4 has the objective to keep the technological capabilities of the companies constantly updated and in touch with international developments - *that is to remain technology-intelligent users* - in order to be able to sustain the position of the companies as major suppliers of high quality products of the Greek military forces. MU5 had similar priorities but during the time of the interview (January 1997), their operational and technology strategy was under evaluation and re-definition.

** To achieve their goals the Greek defence sector *heavily relies on direct technology transfers and external technology acquisitions* for updating and sustaining its technological capabilities. These technologies are transferred with the aim to be absorbed and fully integrated into each company's infrastructure in order to support its production capabilities. All companies apart from MU5 underlined that *materials* know-how is an integrated part of this process.

** The primary missions of MU1-4 R&D divisions are technology transfer in the fields of product design and manufacturing technologies/techniques, new product development (primarily with respect to Greek markets and employing existing materials and S&P technologies) and product and processes improvements. MU5 has very well equipped materials and structures quality control laboratories but no corporate R&D facilities.

** Original R&D is limited and provides emphasis on applied and near-market research for new product introduction (using existing materials and processes), and process or product improvements (using existing materials). Only MU2 and recently MU1 are involved in pre-competitive research as a small fraction of their R&D portfolios. MU2 focuses on advanced structural composites, adhesives and aircraft maintenance technologies while MU1 focuses more on advanced ceramics and functional ceramics (e.g. optics and lenses).

Materials Activities

- The Greek defence sector perceives advanced materials technologies as supporting technologies in a complementary role to its activities and not as a crucial element for building technological and business competitive advantages (also see detailed analysis in Annex 9.5).
- The level of involvement in materials technologies and the level of sophistication of materials strategies varies considerably from company to company with MU5 and the civil division of MU4 the most elementary (simple quality controls and materials testing) and the materials R&D portfolio and activities of MU2 the most

sophisticated (including advanced composites, non-destructive diagnostics, and advanced adhesives).

- Apart from MU2, no other defence company has materials specialised R&D divisions.
- MU2 is the only defence company which has R&D facilities exclusively dedicated to MSE and materials technologies with primary mission to transfer and absorb advanced materials know-how in order to make the company more independent from advanced materials suppliers and to improve or develop a range of specific structural and functional materials used in maintenance and repair of aircraft - the business strategic objective of the company.
- The *class of materials* attracting the interest of each reviewed company varies considerably in accordance to the specialisation field of each company (see Table A9.3 in Annex 9.5)
- All companies are trying exclusively to *improve* (in the best case) *incremental* materials and *focus primarily on structural and a few mixed function materials* (e.g. MU1 - materials for lenses, MU2 - adhesives).
- With respect to *the materials tetrahedron* all the reviewed companies focus almost exclusively on the performance of the materials and on S&P technologies of existing materials. Properties and S&C related research is either carried out internally (sensitive projects) or outsourced to university or other research institutions (MU1, MU2, MU5).

<u>Management practices and core competencies</u>

** The level of awareness of the concept of Kaizen varies considerably between the reviewed companies. Apart from MU1, which consciously employs continuous improvement practices MU3 applies "*common logic practices*" and declined the request for future information while MU2, MU4 and MU5 clearly identified that they do not employ Kaizen practices or that they are not in position to employ them successfully because they are "*public enterprises*" (MU4, MU5).

** Simultaneous Engineering practices in manufacturing and process design are employed only by MU1. MU2, and MU3 also stated that they employ “Closed” SE practices during process or product improvement design, and they pointed out that the technological participation of their materials suppliers was negligible apart from the provision of technological specifications and properties and performance descriptions. These findings suggest that materials suppliers do not have an active technological role in the Greek defence sector, and that the users (defence industry) do not fully practice SE (“Open SE”).

** The concept of technological core competencies has been insufficiently addressed by the Greek defence sector probably because the sector does not operate in real and open competitive conditions. As a result, some of the reviewed companies appear to confuse the concept of commercial competencies with the concept of technological core competencies (e.g. MU2) or the concept of manufacturing competencies with technological competencies[31] (MU1). Materials S&P skills and understanding of existing materials is assessed to be a primary competitive advantage only by three companies: MU3 and MU4 and recently MU1.

<u>Supportive technological competencies</u>

The companies of the Greek defence sector follow converging approaches in a number of supportive technological competencies:

- The defence sector is keen on developing and sustaining in-house simulation and modelling skills.
- Apart from MU5, all the reviewed companies have business unit or division based institutionalised technology intelligence gathering mechanisms. These mechanisms involve teams of experts allocated full-time to the technology information gathering task by employing extensive library and databases networks.
- Instrumentation and new machinery investments policies vary considerably from company to company. For example, MU1 and MU2 operate on the basis of 5 years investment plans including heavy investment of the updating or continuous replacement of instrumentation and equipment of both their R&D divisions and of their manufacturing floor while MU5 just entered the stage of updating after many years of neglect.
- All the interviewed companies face problems with specialised graduate and postgraduate human resources and with skilled technicians and workforce. With respect to technicians and blue-collar workforce, in order to compensate for the inefficiencies of the Greek education system, all the interviewed companies have internal training and re-training schemes. However, since the early 1990s, the Greek State has frozen the employment of new employees (including scientists and engineers) in all public enterprises. The accumulation of knowledge - tacit knowledge in particular - and the introduction of new ideas and skills by new people has already been disrupted in all public enterprises including the enterprises of the defence sector.

[31] Note that commercial and manufacturing competencies may be supplementary to core technological competencies (Klus 1993).

- The majority of the board of directors of all five reviewed companies have an engineering (mostly) or science educational background. This, however, has not been identified as a handicap when it comes to innovation policies and practices. According to all the interviewed officials innovation is halted by external parameters such as the size of the companies, the conservatism of the Greek MOD, the employment condition and others and not by leadership capabilities.

Technological interactions, collaborations and alliances.

** Only MU1 and MU2 have established frequent technological interactions with both corporations and research organisations in Greece and abroad. The other three companies provide emphasis on interactions with mainly international companies while they appear somehow isolated and distant from Greek universities and research/technological institutions.

** Given their size and R&D limitations, the Greek defence companies prefer to enter short to medium term collaborations with mainly international manufacturing companies rather than forming long-term complementary technological alliances with materials/ equipment suppliers. The aim is to learn and transfer established know-how rather than produce new know-how which can ultimately be transformed into new products and markets.

** There are no substantial technological collaborations or even complementary alliances, either with domestic or with international materials suppliers.

** Apart from the case of MU1 and MU2, the military divisions of the public enterprises of the sector have developed very weak or no links with universities and research/technological institutions and appear to be distant from the national R&D infrastructure (universities and other research organisations). Only recently (after 1994), the civilian departments of MU4 and MU5 have started to enter technological collaborations with universities and research institutions. It is not clear if these conditions have been imposed by objective reasons (e.g. the current technological and R&D structure and capabilities of the companies) or by a deliberate choice of the leadership of the companies or the Greek MOD. The existing interactions take the form of common participation in national and international collaborative programmes or the form of R&D contracts (outsourcing).

Financial Constraints For Long-term R&D

- The subsidies provided by the Greek State or the Greek MOD aim either to cover the operational costs and the annual losses of the sector or/and purchase the production of the sector at cost prices - hence much of the deficit of the sector. As such, the sector does not have substantial profits to re-invest in R&D activities.

- Financial constraints and lack of capital are the major obstacles inhibiting the development of further materials R&D activities by the Greek defence sector. Given the lack of capital, the companies of the sector cannot afford to be exposed to long-term, complex and expensive R&D activities such as advanced materials R&D activities[32]. Even though some of them (e.g. MU2, MU1, MU3) have developed third generation R&D activities, its merits are pinned down by the lack of sufficient financial resources.

- Under these circumstances the R&D expenditures of MU2, MU3 and MU4 are dominated by the "net present value" rule, with respect to each individual project's value *and urgency*. Only R&D infrastructure expenditures are made with a long-term view and only if an MOD subsidy has been secured. Apart from selected S&P technologies, MSE technologies receive no special treatment or priority.

Defence Sector Conclusions

The preceding analysis demonstrated that the Greek defence sector perceives MSE technologies only as supporting tools in its activities and not as strategic technologies which provide opportunities for future competitive advantage. As such, the MSE activities of the sector are very limited and very conservative because they are designed to simply support the technological activities of the sector (if at all) and not its business strategies (apart from the case of MU1). In addition, the sector has not adopted Kaizen management techniques (apart from MU1) and does not fully employ SE practices. Further, the sector appears to be technological isolated as it has not developed substantial technological links neither with Greek and international materials producers or component manufactures nor with academic and research organisations.

These findings combined with the current financial inability of the sector to support long-term R&D portfolios **contradict hypothesis H9.2a** by demonstrating that under current conditions the Greek defence sector **has not developed** long-term, multi-levelled and sophisticated materials strategies as an integrated part of its business strategies and thus **cannot provide** substantial technological pull or push to its materials suppliers.

It is notable that the present circumstances are the outcome of externally imposed operating conditions rather than the outcome of internal choices made by the leadership of each industrial unit. On the contrary, the leadership of each unit is trying

[32] For example MU2 finances its R&D activities almost exclusively from participation in R&D collaborative projects.

to achieve the best outcome with the resources it has. At the present state, the R&D infrastructure of the companies and their organisational infrastucture are sufficient to support the current materials activities (incremental structural materials, small scale R&D on advanced structural materials, small S&P improvements), which are of clearly supportive and not strategic role. However, if a strategic decision is taken, the sector has the potential to develop and effectively support sophisticated materials strategies and play its role as an intensive materials user within the Greek system of innovation. Despite the capital availability shortages and the lack of real competition, the units of the sector have a solid corporate structure, they have developed most of the necessary supportive core technological competencies, they have accumulated significant experience on the application and S&P of materials and they have installed a critical mass of R&D activities and infrastructure.

9.3.2: The Construction Industry

"At the moment, the Greek construction market is basically limited to the big projects. When the big projects run out, **R&D** should have to have found new applications and new products".

Hassiotis (1996) on the potential and future of the Greek construction industry.

The construction industry is analysed on the basis of testing hypothesis H9.2b. The sample includes the views of five construction experts with collective experience form the sector (see methodology in Annex 1.1) and three large specialised construction companies. Detailed analysis of the sector including detailed information on its character and operational environment is provided with **Annex 9.6.**

General Characteristics Of The Industry

** The Greek construction industry has been developed in an environment well protected from international competition and is characterised by numerous SMEs mainly active in the buildings and housing industry and 39 (in 1994) large, Ita (8) class[33], non-specialised and/or specialised construction companies which dominate the large scale construction projects and public works contracts.

** Apart from the housing market which is extremely fragmented, the Greek State and the Greek public sector[34] was and still is the main client of the industry with the large scale infrastructure, public works and public agency building projects.

[33] See Annex 9.6.

[34] Including "public goods" enterprises such as the National Power Company.

However, as pointed out by Kalogirou (1991), Kalogeras (1996) and all the interviewed experts the Greek State *has never seen* large scale construction projects as an opportunity for new materials and technology development or transfer. In addition, the Greek State or Greek 'public goods' enterprises used to announce and auction infrastructure and other large scale projects on an irregular basis.

** The conditions of high-uncertainty in which the industry operates has forced the majority of even large and specialised construction companies to adopt an idiomorphic organisational structure assimilating the "**accordion**" function which constricts to a minimal basis of personnel and inventory in times of hardship and expands by contract-based remuneration of human resources, inventory and machinery to meet peaks of demand. According to CONEXP1, 2, and 4, only the companies of the Ita - (8) class created after 1994 and some specialised construction companies are capital intensive and have developed elaborate corporate structures. All the other construction companies, as organisational entities, have a completely elementary form and structure and they retain a strong personal or family enterprise character rather than a real corporate character.

Technological and R&D Considerations

** According to CONEXP1, 2, 3 and 4, there is only a handful of large Greek construction companies (e.g. CON1, CON2, CON3) which base their operational and business strategy on technological competencies based on long-term strategic planning.

** The main technology strategy objectives of almost all construction companies, which have put one in place, *is to consciously remain intelligent technology (and materials) users* and keep at the forefront of the national and (as much as possible) international technological and materials developments.

** Technology and know-how transfers (including materials know-how) is mainly achieved through direct personal human interactions which take place within the frame of construction consortia, not through institutionalised procedures (e.g. reverse engineering activities[35]). Acquired or transferred construction technologies and methodologies and frequently materials know-how is a part of the tacit knowledge and expertise of each company and they are usually exploited to the very limits but in technological terms they are absorbed up to the point of developing effective and economical application capabilities and not down to their very basics (CON1, CONEXP6, PAC2).

[35] As CONEXP3 put it "*... companies invest in in-depth technology absorption and occasionally reverse engineering only if their leadership identifies visible and immediate economic returns and in very rare occasions strategic returns (e.g. the case of CON2).*"

** Construction companies have **no** organised corporate R&D laboratories as those described in chapters 2, 3 and 4 because, as the interviewed experts explained, the necessity for corporate R&D laboratories has only just begun to emerge.

Materials activities

** According to the interviewed companies and construction experts, the Greek construction industry *is more interested in the process* rather than the materials *per se*. Hence, Greek construction companies are regularly and consciously investing in knowing what *new but established* advanced construction materials can do[36], and they are among the first to employ them internationally. But they are not actively involved in the development of new or improved construction materials like, say, their Japanese counterparts.

** For materials know-how, Greek construction companies almost exclusively rely on information provided by their materials suppliers, to certified quality controls and standards specifications. They do not have corporate materials R&D laboratories like, say, Nissan (see chapter 4) dedicated to materials knowledge "digestion" and given that serious problems originating from the utilisation of well-established materials are rare (CONEXP3), they have not developed materials strategies or materials R&D departments as those described in chapters 2, 3 and 4. Unexpected materials problems are usually addressed through trouble-shooting methodologies or outsourcing.

** Since 1994, in order to respond to strict materials regulations and new technological challenges imposed by the implementation of large, EU supported, infrastructure projects, some Ita-(8) class construction companies have established structural materials quality control laboratories equipped with testing machinery able to deliver far more complex tasks. Moreover, a handful of large specialised construction companies (e.g. CON2 and 2-3 others) have established small corporate R&D laboratories and allocated resources, R&D equipment and small groups of engineers for exclusive R&D duties with the aim to solve problems which can not be solved by outsourcing. (CON2). CON2 and other participants refused to provide further information on the current and future portfolio of these small R&D groups.

Management practices and core competencies

** Construction companies are not consciously aware of the concept of Kaizen. As CONEXP1,2,4 and 5 pointed out, all management procedures and methodologies employed by even the large construction firms are based on experience, they are not

[36] Emphasis in primarily given to materials properties and performance evaluations of structural materials and in particular on the **implementation** and the **in-situ S&P** of advanced but well-established materials.

institutionalised and are strongly related to the attitude or the perception of the leadership of each company. However, either instinctively or under the concept of "common sense" the interviewed construction companies in practice employ many Kaizen elements such as Simultaneous Engineering, learning- by-doing, team work and learning by interaction (an element which they have developed to perfection).

** Simultaneous Engineering practices (simultaneous selection of materials - construction method) are employed on a regular basis during the design stage of the construction but materials suppliers are not brought in which indicates that construction companies employ only "closed SE" practices at best.

** According to the interviewed experts, the majority of the Greek construction industry (including some large, Ita class companies) have not identified and invested in technological core competencies. On the contrary, the reviewed large specialised construction companies have identified as paramount technological core competency their ability to handle, apply and process in-situ conventional and new construction materials. However, as CONEXP3 highlighted, all this knowledge is the product of empirical experience and as it is not officially recorded (there are no case study records or patents) is strictly **tacit** knowledge confined to "... *the heads of specific individuals*".

Supportive technological competencies and human resources policies

- Construction companies follow converging approaches in a number of supporting technological core competencies.
- The large specialised companies regularly invest in equipment and new machinery. CON1, CON3 and especially CON2 identified it as their main source of competitive advantage. The non-specialised companies invest only when "... *absolutely necessary*" (CONXP3, 4).
- With respect to simulation and modelling skills, even the large specialised companies prefer the solution of extensive outsourcing. They take advantage of the abundance of the cheap and high quality software and modelling companies offered by the Greek domestic market. Only CON2 has plans to develop an internal simulation and modelling department to deal with "sensitive" projects.
- Greek construction companies have no institutionalised technology intelligence gathering mechanisms as those described in chapter 4. Technology intelligence gathering (including materials technologies) is rather project related and it is carried out through experienced senior engineers appointed for a specific period of time to the task of gathering technological and materials information for new but

established materials and technologies; not for emerging technologies or experimental materials (CONEXP3).

- CON1 and CON2 have organised mechanisms for gathering and evaluating current and future customers needs in order to be able to prepare technologically prior to the emergence of the need. However, as CONEXP1,3,4,5 identified this is the exception and not the rule.

Human Resources Policies

According to the interviewed construction experts the overwhelming majority of the Greek construction companies have no specific or formulated human resources policies for senior or executive level employees and they suffer from *the high mobility* of senior and experienced engineers and senior and skilled technicians in the sector. Given the tacit and not institutionalised character of the accumulation and expansion of knowledge, many corporate competencies abilities to innovate are based on the skills of these people. Therefore the high mobility of senior engineers and executives has a detrimental effect on the design and implementation of long-term strategic planning and the management and protection of essential core competencies which are mainly tacit in nature. On that point, specialised construction companies (such as CON1) make every effort to have a permanent core of engineers and skilled technicians and labour workers and develop internal education schemes but as CONEXP1,2 and 3 pointed out this not the case of the average Greek construction company.

Technological Interactions, Collaborations and Alliances

** There are no long-term technology-based alliances among Greek construction companies or among Greek and international construction companies mainly due to direct conflicts of interest. However, the constant interaction of many large construction firms within large construction consortia during the design, development and execution stage of large infrastructure projects and the high mobility of senior engineers, replace much of the benefits of formal technological interactions as experience and know-how is at senior levels.

** The establishment of complementary technological co-operations and alliances between materials suppliers and construction companies in Greece is rare to non-existent. The interaction between the two industries is a commercial one and it is described by frequent (in the best case) exchange of technological information concerning specifications and data on the properties, performance and standards of the available materials. Some large materials producers (e.g. C1 and C2) have made efforts to establish formal technological co-operations but only a handful of construction companies have responded.

** The interactions of construction companies with machinery suppliers are frequent but their nature is purely a commercial one. Only CON2 has established complementary technological alliances with their heavy machinery international suppliers. CON2 is the first construction company which exclusively tests completely new and innovative machinery in real working conditions. In return, CON2 provides its machinery manufacturers real operational performance feed-back including significant operational and technological information[37].

** The construction industry has not formed any substantial technological or R&D collaborations with universities and research/technological institutions. Interaction with universities is frequent (consultancy provision, trouble-shooting, involvement of academics in the design or even planning stages of difficult projects) but it does not involve any significant technological or R&D collaborations. Moreover, the sector does not enjoy the services of a research or technological institute dedicated to construction materials and technologies[38] and appears to be isolated and insufficiently supported by the national innovation system and its supporting mechanisms. Serious weaknesses and voids have been identified in the fields of standardisation and certification of materials, technologies and structures, and in the research infrastructure supporting the sector.

Financing R&D and Technological Innovation

Two distinctive groups of companies were identified:

** The first group concerns a handful of large companies which aim to develop corporate R&D activities and technology strategies as an integrated part of their operational strategies. So far, all the technological activities of these companies have been exclusively financed through corporate resources (apart from the rare cases of participation in national / international R&D programmes). These expenditures are invariably seen as strategic investment and therefore they are constantly monitored and evaluated.

** The second group involves the majority of the Greek construction industry which perceives investments in technology as a "necessary evil" (CONEXP4,6). When investments are made, these companies invest under the concept of the "net present value" rule, and always with respect to the immediate needs of each individual project (CONEXP1,2,3).

[37] Note that this is the second case where a Greek company has such an achievement. The first and very similar case was the case of M2 and M3 presented in section 9.2.1 and 9.2.2.

[38] Apart from CONEXP3 which operates on a temporary basis.

Construction Sector Conclusions

The preceding analysis revealed that the Greek construction sector is aware and appreciates the technological and commercial advantages of advanced and incremental materials and hastens to employ them when they become commercially available and when cost considerations allow it. The sector however, has **not** realised its potential as a strategic materials final user and it is **not** currently in a position to develop, support and sustain complex advanced materials strategies mainly due to internal structural, organisational and **institutional** weaknesses. Even the large, technologically specialised companies have not fully recognised the importance of the development and commercialisation of advanced materials (or construction systems based on advanced materials) and provide more emphasis on construction process techniques rather than materials and integrated materials - processes systems. Thus, **hypothesis H9.2a** has been **verified** in the case of the construction sector.

9.4: The view of industry for the national MSE and technology policies and the mechanisms for their support

When the reviewed companies/sectors were asked to provide comments on the orientations and the elements of the national MSE policies, their comments provided a broader view of both materials and general technology policy issues. Detailed presentation of the views of each sector is accordingly provided in Annexes 9.1 to 9.6 The following list summarises the national materials and technology strategy points where the reviewed companies/sectors identified key strengths or weakness and shortcomings. The most important points are:

- Identification of specific materials and technological priorities supported consistently with specialised actions over long periods of time. This element was picked by all the reviewed sectors and it was connected with the issue of industrial policy priorities and the issue of national R&D infrastructure priorities. EKVAN is viewed as a positive development but insufficiently addressing the existing national materials strengths.
- The provision of information mechanisms on international technological trends and developments. This point was also picked by all the reviewed sectors. The construction sector in particular, pointed out that the issue of identification of priorities and information on international developments in construction materials technologies is crucial for the sector because there are no official information

gathering and diffusion mechanism for new and advanced materials and what they can do for construction.

- Provision of sufficient supportive R&D infrastructure: it has been demonstrated that the national R&D infrastructure still has major gaps. The final materials users sectors are in isolation as there are no construction and defence dedicated research institutions or organisations. The reviewed companies / sectors called for

  further support and enrichment of national R&D infrastructure facilities tailored to the needs of the reviewed sectors including the strengthening of RI1 and RI2 (the *cement and consumer ceramics sectors and some construction experts only*).

- The construction sector highlighted the need for the establishment of a national Construction Technologies Institute as an extension or institutionalisation of the CONEXP3 laboratory.

- The promotion and support of industrial clusters and of industrial networks among complementary sectors or industries on the basis of long-term planning, something which some sectors (commodity ceramics and cement sectors) have taken the initiative to create without any substantial State support. Moreover, all companies / sectors identified that the current arrangements of the national innovation system (e.g. priorities and implementation of the NCRDP, the 1892/90 investment law etc.) have insufficiently addressed the issue as they favour individuals and not complementary industrial sectors and technologies.

- Provision of supportive facilities: standards policies, regulations, information diffusion mechanisms and effective legislation supervision and enforcement mechanisms were requested by all of the reviewed companies. That included:

  ✓ The urgent need for standardisation policies and effective certification mechanisms for products and equipment. The cement and construction industry pointed out that ELOT has done remarkable work in the certification of manufacturing, tangible products and mechanical engineering works. However, in civil engineering works, ELOT's involvement is still inefficient or elementary and standardisation is in its beginning. In addition, M2, M3, C2 and MU2 pointed out that ELOT is unable to design and support large scale standardisation policies as a follow-up of the national materials or other technological priorities due to lack of institutional framework and due to insufficient infrastructure and severe shortages of specialised personnel[39].

[39] These findings have been verified by ELOT officials.

- ✓ Effective supervision and survey mechanisms on the application of standards and construction specifications and enforcement of the relative legislation (mainly highlighted by the metals, consumer ceramics and construction sector).
- ✓ The enforcement of effective quality control regulations not only on materials producers but on materials users as well (all materials producers – ceramics sector in particular).
- ✓ Trade regulations, that is, the blockade of the unregulated imports and utilisation of dubious quality but cheap and uncertified products from non-EU countries (all the materials producers). This point was particularly highlighted by C3, C4, M5St, M1, M5 and M3 because the mainstream products of these companies are commodities which have been hit hard from the unregulated importation of low quality materials from East European and other non-EU countries.

- Provision of low cost capital and tax incentives for technological innovation. Given that all the reviewed sectors pointed out that the Greek financial markets were unprepared or unwilling to be involved in the finance of technological innovation (verifying the findings of chapter 8), they unanimously requested arrangements for low cost capital and effective tax incentives. M2 added that there are some incentives and mechanisms but the bureaucracy is immense. That inhibits any non-public sector company from seeking financial assistance from public sources.
- The construction and the defence sector (materials users) requested the provision of long-term planning in State procurements and for long-term planning of public works announcements.
- MU5 underlined the immediate need for a national strategy in shipping and shipbuilding and the creation of a relative and specialised supporting infrastructure[40].

With respect to the defence industry the last three issues were perceived as the main obstacles inhibiting the sector to develop more intensive R&D activities and commercialise its results. In particular, the request for long-term capital for R&D investments and "the way the existing capital is administrated" (MU3) is regarded as

[40] As MU5 explained,

"Greece has the potential for developing many advanced offshore materials because it has both the production units and the climate advantage for the processing of materials which other countries (e.g. Norway) do not have. But there is a lack of strategic decision at national level to support R&D in materials for offshore and marine applications. Isolated companies, however, can not go far on their own."

the number one obstacle in the defence sector for further development of R&D in both materials and many other technologies.

Moreover, the request of both the ceramic producers sectors and the construction industry for the enrichment of the national R&D infrastructure with structural materials oriented institutions, verifies the finding of chapter 8 that the present national research infrastructure is unable to meet the needs of the reviewed sectors and is unable to sufficiently support the majority of the national materials priorities (structural materials), because there are no sufficient national R&D activities and facilities denoted to these materials fields.

In addition it is notable that neither of the two reviewed metals sectors nor the defence sector have requested the strengthening of the existing national research infrastructure and the promotion of research networks and institutions. This is in direct contrast to the cement and consumer ceramics sectors and demonstrates the remoteness (or the isolation) of the sectors from the national research infrastructure.

Finally, apart from the defence industry which operates on the basis of internationally monitored standards and regulations, all the other sectors put emphasis on issues such as standards and trade regulations and on general technology policy issues rather than "pure" materials issues. Given their size and international connections most of the reviewed materials producers have developed their own means to compensate for the weaknesses of the national innovation system (e.g. education policies and support for competitive research). However, they cannot compensate for national institutional arrangements and procedures.

9.4.1: National Collaborative R&D Programmes and the view of industry

Among the reviewed sectors and companies, the cement sector and the consumer ceramics sector have the highest levels of participation in both national and international collaborative R&D programmes. In addition, M2 and M4 (ferrous metals), M3 (non-ferrous metals), MU1 and MU2[41] (defence industry) have regular participation in almost all the national R&D collaborative schemes and the Brite/Euram programmes.

This comes as a direct result of the well-defined R&D strategies of these companies /sectors and the strong links they have developed with Greek universities, research /technological institutions and the national R&D infrastructure in general.

[41] MU2 provides emphasis to international collaborations because the budgets of the projects are bigger and the participation terms reflect better the needs of the company.

According to the cement industry (C1 and C2) and the consumer ceramics industry (C3, C4, C5, C6), two direct positive consequences of the application of the national R&D programmes are the updating of the research capabilities of Greek universities and the re-focusing of the research interests of Greek academics from pre-competitive to applied and near market research which assisted the formation of links between companies and universities/research institutions. In addition, according the M3 and M2's opinion the implementation of the programmes has created notable R&D leverage in terms of spreading risks and R&D expenses, training and education of human resources, and subsidisation of R&D infrastructure.

Moreover, C1, C2, M2 and M3 underlined that the *early stages* of the national R&D programmes offered substantial financial incentives for participation because they subsidised the acquisition and deployment of R&D laboratories and research equipment (R&D physical infrastructure). During later stages, *the primary benefit is the participation per se*, that is the *interactions* with other companies and research organisations, the creation of human networks and the exchange of ideas and information.

According to the all the interviewed participants, one of the main disadvantage of the NCRDP programmes is their implementation which does not provide and/or is unable to support any specific or sector-related technological priorities (e.g. targeting structural metals) and does not favour the development of industrial networks or clusters because the participation requirements do not pre-require them. Usually one industrial user is sufficient to support a successful application. But as C3 put it, that should not deter companies from participating because "*If a company wants to benefit from national R&D collaborative schemes, then the opportunity is there. Even though we do not see a specific materials strategy cutting through these schemes, many good things can come out of this participation.*" C6 and C4 took the issue one step ahead and revealed that the horizontal character of the national R&D collaborative schemes, despite their implementation weakness can be flexibly used by participating companies in order to subsidise their immediate R&D needs. As C4 explained: "*... if we have an emerging local problem which is not related to cutting edge technologies or materials research , the parent company will (most likely) not finance it. Thus we have to cope with it on our own and hence we try to utilise the support we receive from participation in the national collaborative schemes.*" In other words, a firm can use the NCRDP to satisfy its own needs.

In view of the above, the current implementation arrangements of the NCRDP cannot uniformly support vertical technological priorities but only horizontal ones. That **confirms** the finding of chapter 8 that the current arrangements of the NCRDP have reached their beneficiary ceilings and they are unable to consistently support the national materials priorities.

On the other hand, M1, M5St and M5 (ferrous and non-ferrous metals), MU3, MU4 and MU5 (defence industry) and the construction sector have a very poor or no participation record in national and international collaborative programmes.

Given that M1, M5St and M5 have not developed close ties with academic institutions or research organisations, they have difficulties in getting aligned with the prerequisites of the national collaborative schemes. The interviewed experts didn't provide any further comments on the national R&D collaborative schemes.

The participation of the defence sector (military divisions) in national and international R&D activities was limited and since 1994 it has further declined. With respect to the defence sector, apart from MU1 and MU2 which frequently participate in both national and international collaborative R&D programmes (MU2 is the only company which has a fully developed participation strategy), the other companies have no particular interest in these activities because early participation in collaborative projects "*...did not provide the expected results*" (MU3). MU5 pointed out that the company has never participated because "*... we lost out in the proposals competition*". However, the civilian division of MU4 and MU5 revealed a growing interest in creating links with research organisations and participating in R&D collaborations.

In addition, given that most construction companies do not have R&D activities (basic requirement for participation in the NCRDP) and given that they have not formed R&D links with universities and other research organisations, the participation of the construction sector in the NCRDP is very low[42], especially when it comes to the participation of general orientation construction companies.

Nevertheless, both the interviewed construction experts and all the reviewed defence companies pointed out that the horizontal character of the NCRDP and their participation pre-conditions do not take into consideration the special characteristics and needs of the two sectors[43] and they have excluded them from State R&D subsidies and other R&D supportive schemes[44]. Moreover, due to their operational

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[42] Also See : Technical Chamber of Greece (1992). *Investigation and evaluation of the EU framework programmes*. Athens, April 1992.

[43] Chapters 7 and 8 have predicted that the implementation of the national R&D programmes had the potential to endanger the participation of many crucial for the Greek economy industrial sectors. The defence and the construction sector provide a tangible example of the argument.

[44] MU5 in particular, underlined that there are no NCRDP which take into account the special needs of the shipbuilding industry in Greece.

specifications, both sectors can not take advantage of other forms of State subsidies such as the 1892/90 investment law (analysed in chapter 8).

Finally, participation in international R&D collaborations such as the Brite/Euram programmes has been successful and fruitful for the cement industry, the consumer ceramics industry, M3, M2, MU1 and MU2. As C1 put it "... *the results of Brite/Euram programmes are related the needs of Greek industry if Greek industry participates as a primary participant. In our case, this is the case.*" The construction industry has only 4-5 entries in Brite/Euram programmes. The Greek participation in Brite/Euram programmes receives extensive analysis in chapter 10.

9.4.2: Industry and interactions with public agencies

All the reviewed sectors pointed out that there are no official routes or institutionalised mechanisms for direct interactions with GSRT or other relative public agencies. In some cases (e.g. the cement, consumer ceramics, M2, and the non-ferrous metals producers – M3 and M5) interactions and exchange of ideas take the form of occasional submission of industrial or technology policy proposals and occasional direct interaction with GSRT or Ministry of Development officials (participation in committees) for the design of the directions of the national technology policy priorities.

In the case of the defence sector, the interviewed officials pointed out that there are no links between GSRT and the industry because the sector operates under the direct jurisdiction of the Greek MOD. As underlined in chapter 7, GSRT has made efforts to establish communication with other public agencies but has not yet achieved the required level of communication and co-ordination. In addition, all the interviewed construction experts expressed their concern for the total break of communication for technological issues between the construction sector and the Ministry of Development. Apart from two 1994 technology foresight reports dedicated to the sector, there is no GSRT or Ministry of Development division dedicated to the needs and the technologies of the construction sector. According to CONEXP3,4 and 5, even the Ministry of Public Works has insufficient contacts with construction companies and it does not have a specialised agency dedicated to the technological support of construction companies nor with the promotion of the internationalisation of the Greek construction sector. According to CONEXP4, this situation has been created because the Greek State sees the construction sector as a labour intensive sector and not as a technology intensive sector and it does not realise its technological potential. Thus, given that the Greek State does not exploit the opportunity to demand the application of new technologies and materials during the implementation of public contracts, the great potential of the sector is wasted, critically affecting the future internationalisation efforts of the sector and its future abilities to compete successfully with international competitors even in domestic markets.

9.4.3: Industry and Higher education policies

All the reviewed sectors pointed out that, with respect to the employment of graduates, Greek universities supply scientists and engineers with a good general background which is, however, rarely sufficient for the specialised needs of the each sector. Mechanical engineers are employed as a matter of deliberate policy as materials specialists (defence industry, construction industry) because they have a more rounded education background in MSE. Further internal training is required to build upon the general background of the employed graduates. Hence, all the reviewed sectors declared that they would welcome the establishment of postgraduate specialisation courses and continuous education schemes and some of them (e.g. cement sector) are willing to actively support their operation.

In addition, all the reviewed sectors identified serious weakness in the technical education level. Given the decline of traditional apprenticeships, there is a severe shortage of skilled technicians which is perceived as a major drawback inhibiting technological innovation in Greece. The large companies compensate with internal education schemes. SMEs with limited resources are clearly at a disadvantage.

Finally, a severe lack of graduates with rounded education on management-science/technology-finance principles was identified. In some of the reviewed companies, the existing leadership and middle-level management has met these qualities through learning-by-doing and learning-by-interacting procedures. In some other companies however, lack of leadership and/or middle-level management with these qualities has been identified as the origin of serious perception problems related to corporate materials and technology strategies.

9.4.4: Industry and patents

With the exception of M2, which is a technology developer operating on the basis of unique in the world technologies developed by in-house R&D activities, all the reviewed companies/sectors pointed out that they do not have formulated patenting strategies. Most of them deliberately avoid patenting, publishing papers or developing mechanisms necessary for the support these efforts (e.g. R&D strengths).

M3, C4 and C2 pointed out that they are interested in patents but when something worthy appears the patent is internationally registered by the parent company and its use is distributed to all sister companies.

The ceramic producers, C1, M5, M4 and the defence sector pointed out that the nature of their R&D activities is very applied and competitive. Hence, the outcome is incremental improvements in materials, products, processes and occasionally machinery, which are difficult and expensive to patent (in terms of originality) and easy to copy by competitors. Therefore, all innovations are kept strictly inside each company and become a part of the technological core competencies of the company. In the case of the construction sector, all innovations and S&P ingenious solutions are even codified and recorded; they are kept strictly inside the company and in the heads of company's engineers[45] (unanimous attitude).

9.4.5: Interactions with banks and financial markets

The need for provision of low cost capital for high technology investments by the Greek financial markets has been picked invariably by all the reviewed companies and sectors (both materials users and producers). Moreover, they pointed out that the Greek financial markets have not yet developed efficient mechanisms for the provision of patient capital or the financing of technological innovation. Neither banks not venture capital companies have developed the necessary mechanisms to address the issue of financing technological innovation. Thus, they prefer to avoid the issue or provide priority to credibility issues such as the size and the assets of the company / applicant. Under these conditions, large corporations face no problems raising capital from the Greek financial markets. High-technology SMEs however, face serious difficulties in their efforts to secure capital from the Greek financial marks.

[45] In addition, the development of patenting strategies necessitates the existence of strong R&D and public relationships strategies which many companies (e.g. defence and construction sector) do not have.

In addition, it is notable that there is considerable distrust between the Greek banking sector and some industrial sectors. For example, the banking sector has a strong interest in investing in the construction industry but according to the interviewed construction experts banks do not exhibit any understanding for the special needs and characteristics of the sector. Moreover, many companies (e.g. M3, C5, M1) prefer to secure capital from international sources rather than the Greek financial markets.

Finally, there are no substantial links between venture capital companies and any of the reviewed sectors which inhibits the incubation and growth of specialised, high-technology SMEs acting as materials and components suppliers of the Greek final materials users (or even producers).

Given that the Greek State has not developed any mechanisms exclusively dedicated to the long-term financing of technological innovation, these conditions create additional problems to the internationalisation efforts of the reviewed sectors and the development of long-term business strategies based upon long-term materials and other technological competencies.

9.5: Final conclusions and observations

Materials producers: Hypothesis **H9.1** has been **fully verified** in the case of cement and commodity/consumer ceramics producers and the case of non-ferrous metals producers. It has been **partially verified** in the case of steel producers. These sectors perceive MSE competencies as a basic foundation for competitive advantage and they have developed (or they are in the process of developing) materials strategies on the basis of the international codes of practice in support of their technological and operational activities. High international exposure, high levels of industrial interconnections and operation in world market competition conditions are regarded to favour the dedication to these perceptions.

A visible risk is the current orientation and structure of the R&D activities of these companies. As it is closely tailored to the conservative technological requirements of each company, it is expected to be increasingly difficult to change gear into more demanding conditions.

Materials Final Users: Hypothesis H9.2a and H9.2b. Hypothesis **H9.2a has been contradicted** (the defence sector has not developed strong MSE strategies) while hypothesis **H9.2b has been verified** (the construction sector has not developed MSE strategies and has weak technology strategies). The reviewed final materials companies are intensive materials consumers but they **have not yet** developed the ability to identify and extensively capitalise on materials competencies and provide the necessary technological pull-push effect on their domestic (and international) materials suppliers. Thus, the industrial problem of lack of vertical integration in Greece is also a domestic MSE and technological problem which has not yet been officially identified and addressed by the national materials and technology policies.

Verification of Hypothesis H9.3. The combined findings of all the reviewed sectors prove that there are significant MSE strategy variations between companies operating under Greek (or mixed) ownership and companies operating as subsidiaries of multinational firms. That is easily visible by contrasting the strategies of C4, M3, and C2 with the strategies of M5, M2, C1 and the materials users sectors. The first group (subsidiaries) deliberately operate on the basis of established or critical technologies and abstain from pre-competitive materials research, since R&D on new materials and emerging technologies clearly remains the responsibility of the parent company[46]. The notable differentiation between the reviewed sectors has multiple origins. The following relationships were identified:

1. Type of ownership: Companies or sectors operating under State control (defence sector, MU5) have the weakest materials strategies. On the contrary, privately owned companies (or sectors dominated by privately owned companies such as the ceramics sector) have developed strong technology and materials strategies. The case study of M2 however, demonstrates that under certain conditions such as *high international exposure*, public enterprises can develop materials competencies and be competitive in international markets.
2. International exposure: The level of international exposure of each sector / company is a major source of differentiation. The higher the level of international exposure (in terms of targeted markets or ownership) the more sophisticated and mature the materials strategies. The lower the international exposure (e.g. defence and construction sector, steel producers) the weaker and less developed the MSE strategies.
3. Industrial networks: That is the level of communication and co-operation developed among companies of the same sector or with companies of complementary sectors. Clearly the cement and the consumer/commodity ceramics sectors have developed high levels of internal bonds and communication levels. The metals sector has not, but operates as a group of isolated units.

[46] That brings forward the argument of chapter 3 - "He who controls materials controls technology"- and the argument of chapter 4 that materials know-how is not a tradable asset.

These three factors have cumulative and complementary effect. For example the cement and consumer/commodity ceramics sector compete in international markets and they have high levels of foreign co-ownership and the strongest materials strategies. On the other hand, the defence sector (weak materials strategies) has low levels of international exposure, the companies of the sector are public enterprises serving internal markets and they operate as isolated units rather than complementary technological clusters. The case study of M2 (strong materials strategies) demonstrates that international exposure is more important than type of ownership.

Verification of Hypothesis H9.4. The combined findings of all the reviewed sectors and of individual companies have verified the results of the NRC study (1989) on the connection between MSE strategies and business competitiveness. As in the NRC study, there is a direct connection between the level and the sophistication of the applied MSE strategies and the financial performance of the sector / company[47]. The sector / company which has chosen to capitalise on advanced MSE strategies (and efficiently support them) as a response to competition intensification is profitable over a long-period of time (i.e. cement sector, non-ferrous metals, M2). The sector / company which has chosen not to capitalise on advanced MSE strategies (and efficiently support them) as a response to competition intensification is facing persistent losses (i.e. the defence sector, M1).

Verification of Hypotheses H9.5 and H9.6. The case study of the construction sector and of MU5 (shipbuilding) has verified the arguments of chapter 8 and the working hypotheses 5 and 6 of chapter 9 that the participation preconditions and the implementation characteristics of the NCRDP have excluded industrial sectors important for the Greek economy. Moreover, the converging opinions of all the participating sectors have verified that both the implementation of the national R&D schemes and the current institutional arrangements are designed to provide support in individual sectors; they are not designed on the basis of supporting complementary industrials sectors, networks and technological clusters, hence the unanimous request for networks support from all the reviewed industrial and academic sectors.

The verification of hypothesis H9.5 and H9.6 has wider implications for the design and implementation of the Greek national materials strategies. The present conditions of the "exclusion" of the construction sector from the NCRDP and the deficient support of both the defence and the construction sector by the national R&D infrastructure, apart from the negative direct consequences for the long-term competitiveness of the sectors, may jeopardise the commercial and technological future of a significant portion of the national materials strategies and priorities. Given

[47] The construction sector was not reviewed in the NRC study and it is excluded from the comparison.

that five major national materials priorities (see section 8.2) target the development and commercialisation of incremental and new construction materials, it follows that these efforts would need to be supported not only by materials producers but also by intensive materials users ready to play their R&D and commercialisation role and provide the necessary technological and commercial pull-push effect. But all the preceding information leads to the conclusion that the construction sector is unaware or simply not ready to respond to the challenge. This is a major inconsistency of the Greek technology and materials strategy and reveals a major weakness of the Greek innovation system firstly identified in chapter 8 and verified by the converging opinions of all the participating sectors: the inability of the system to effectively support integrated and technologically complementary industrial sectors / clusters rather than isolated companies and organisations.

In addition, by combining all the preceding information and conclusions some additional observations were made possible:

** The Greek materials final users and some segments of basic metals producers have developed the weakest links with the national R&D infrastructure and have the lowest levels of technological communication with other sectors and within their own sector (defence sector). Given that these sectors have the weakest MSE strategies, that imposes additional obstacles in their efforts to strengthen their MSE capabilities and put them in the service of their business objectives.

** Both the defence and the construction sector (materials users) revealed that for technologically demanding applications the majority of the employed materials are imported because Greek producers either do not or cannot produce them. For conventional applications most of the conventional ceramics and metals are produced in Greece while most of "special" and advanced materials are imported. That imposes a challenge and a motive to Greek materials suppliers to diversify from conventional to advanced materials for mainstream applications. The SlimDek steel developed by British Steel provides a very good strategy illustration example.

** All the reviewed industrial sectors highlighted the need to support industrial and technological clusters and networks as a national technology policy priority. That request reveals a fundament flaw of the Greek national innovation system. According to Metcalf (1991), it may be more important for the rate of progress in a technology not to spend more resources in R&D but instead to build communities of interaction between the different organisations articulating the technology in question. Who speaks to whom, in what frequency and to what purpose may be the crucial factor in determining the returns from an R&D programme (Metcalf 1991). This point is fully endorsed by the Japanese materials and technology policies, it has been adopted by the Greek ceramics and construction sectors but it has been underplayed by the national technology and materials policies.

** The Greek State invests huge amounts of public money as contribution to the national R&D collaborative schemes in its effort to encourage Greek companies to develop and support sustainable R&D activities. Nevertheless, the present investigation demonstrated that despite the rather isolated case of M2[48], public enterprises (e.g. the defence sector including MU5) are among the weakest in terms of MSE strategies. In addition, large public enterprises (most of them public goods monopolies) of low international exposure such as the National Railways and the National Power Company have a very low record of participation in the national collaborative R&D schemes and a very low record of in-house R&D activities (see also Figures A7.3-6 in Annex 7.1). Given the powerful influence of the Greek public sector in the Greek economy, and the subsidisation these companies receive, this is a paradox especially in the case of intensive final materials users (potentially advanced metals and ceramics) such as the National Power Company which has both the financial capabilities and the technological and operational needs[49] to be heavily involved in extensive materials and other emerging technologies R&D. The National Power Company however, does not have any significant internal R&D capabilities because "*..had the company developed extensive R&D activities, the results of these activities would seriously endanger the internal balances of the company* (PAC6 1995, verified by PAC3 1996).

This statement strongly indicates that issues of internal organisational structures and *the distribution and balance of power* strongly affect the development of materials and other technology strategies. This point is identified as a major opportunity for future research.

Finally, in order to make *a connection with the central hypothesis (H1)* of the thesis, the analysis of the private sector materials strategies demonstrated that at corporate level the international "codes of practice" can be and have been successfully applied and implemented by Greek corporations[50] operating within the Greek national system of innovation.

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[48] Which notably competes in international markets.

[49] Department of Energy (1995). 'Sustainable Energy Strategy: Clean and Secure Energy for a Competitive Economy'. Government Printing Office, Washington D.C. -- Department of Trade and Industry (1995). 'Progress Through Partnership Reports: The report of the Energy Panel'. HMSO, London. -- Industrial and Development Studies Company (1995). '*Forecasting Study of Technological Consequences for 2000 and 2010: The Energy Sector*. General Secretariat of Research and Technology, Athens.

[50] E.g. the cases of the cement and consumers ceramics sectors and the case studies of M3, M2 and MU1.

On the other hand, in the case of companies/sectors with weak MSE strategies, the origins of the problem arise either from endogenous structural, organisational and institutional weaknesses (M1, M5St, MU5, construction sector) or from externally imposed institutional and operational limitations (the defence sector) which do not permit the development and efficient support of multi-levelled and "aggressive" materials strategies.

Given that the international "codes of practice" can be successfully adopted and applied as a conceptual entity even in the case of industrial sectors or corporations operating within weak national innovation systems, if these companies/sectors wish to build competitive advantages through the development and commercialisation of advanced materials competencies, important institutional changes have to occur first or simultaneously take place with the design of new materials strategies.

CHAPTER 10: Materials Science and Engineering in Greece and International R&D Collaborations

10.0: Introduction

Chapter 10 provides an analysis of the participation of Greece (companies and research organisations) in international R&D collaborative programmes focusing in particular on the Greek participation in the *Brite / Euram* programmes, the EU materials and industrial technologies specialised programmes. The aim is to derive conclusions and to make policy recommendations with respect to the level and the characteristics of the Greek participation through the evolution of the Brite/Euram programmes and the impact of the participation (tangible and intangible benefits) on the national innovation system and the Greek economy. To achieve these goals two working hypothesis are employed:

> Hypothesis **H10.1**: Given the high overall participation record of Greece in international R&D collaborative activities (see section 10.3), the significant improvement of the national R&D infrastructure during the 1986-1992 period and the notable increase of corporate R&D activities during the same period, it is hypothesised that the level of Greek participation in Brite/Euram programmes would be steadily rising or remain stable but high.
>
> Hypothesis **10.2**: It is hypothesised that the tangible results of the Greek participation in the Brite/Euram programmes are directly related with the type and the nature of the participants (e.g. academic institutions or corporations). We would expect "pure" academic institution participations to create limited tangible benefits, while we would expect private corporation participations to create substantial tangible benefits for the participants and the Greek economy.

In order to test these hypotheses, chapter 10 commences with a brief presentation of the EU Framework Programmes and their connection with the Brite/Euram programmes (section 10.1). The chapter then proceeds with a brief presentation of the evolution of Brite/Euram programmes providing particular emphasis on emerging conditions (e.g. strategic aims and participation pre-conditions of the programme) affecting current and future Greek participation (section 10.2).

The chapter then proceeds with a presentation of the Greek record in international R&D collaborations *(section 10.3)* followed by section 10.4 which provides an analysis of Greek participation in the Brite/Euram programmes and tests the working hypotheses. The conclusions are provided in section 10.5 and the policy implications and recommendations in section 10.6.

10.1: The EU Framework Programmes

The decline of European competitiveness in high technology products and services during the 1970s and early 1980s was a major source of concern for the European Community (EC) and then the EU. During the 1984-1998 period, the response was the formation and launch of four consecutive Framework Programmes with the mission to enhance the cohesion of the EU, accelerate the integration of the Member States and strengthen the technological capabilities, and thus international competitiveness, of European industry.

For presentation reasons, a brief summary of the first three European Community Framework programmes is provided with **Annex 10.1**.

The *fourth Framework Programme* (1994-1998) for European research and technological development coincided with the signing of the Maastricht Treaty when the EU R&D policy gained a consistent horizontal character cutting through all the major sectoral[1] EU R&D policies. Aimed at helping to restore the position of Union firms at the forefront of the world economy, the programme allocates 12.3-13 billion ECUs in funding for R&D projects (approximately 5% (in 1997) of the total EU budget). The fourth Framework Programme is summarised in **Table 10.1** and comprises four lines of activities:

1. R&D programmes in enterprises, universities and research institutions within the EU spread over 8 priority fields and 15 technological fields (see Table 10.1);
2. R&D co-operation with third countries and international organisations;
3. Promotion of the dissemination and exploitation of R&D results (i.e. conversion of scientific breakthroughs into commercial successes);
4. Stimulation of the training and mobility of researchers.

While the basic policy priorities (e.g. human resources, support of technological and industrial competitiveness) of previous framework programmes (the third framework in particular) remained unchanged, the fourth framework programme put considerable effort into enhancing co-ordination and rationalisation of R&D in the EU by making better use of its results, promoting SMEs participation and increasing help into research on the implementation of EU policies.

[1] Environment, energy, transport, agriculture, health, industrial and materials technologies etc.

Field	Funding In million ECU	Field	Funding In million ECU
ACTIVITY 1 – RTD AND DEMONSTRATION PROGRAMMES	**10686**	**V. Energy** 11. Non-nuclear energy 12. Nuclear fission safety **13.** Controlled thermonuclear fusion	**2256** 1002 414 840
I. Information and communication technologies 1. Telematics 2. Communication Technologies 3. Information Technologies	**3405** 843 630 1932	**VI. Transport** 14. Transport	**240** 240
II. Industrial and Materials Technologies 4. Industrial and materials technologies 5. Standards Measurements and testing	**1995** 1707 288	**VII. Targeted socio-economic research** 15. Socio-economic research	**138** 138
III. Environment 14. Environment and climate **15.** Marine science and technologies	**1080** 852 228	ACTIVITY 2 – INTERNATION COOPERATION	**540**
IV. Life science and technologies 8. Biotechnology 9. Biomedicine and health **10.** Agriculture and fisheries	**1572** 552 336 684	ACTIVITY 3 – DISSEMINATION AND EXPLOITATION OF RESULTS ACTIVITY 4 – TRAINING AND MOBILITY OF RESEARCHERS	**330** **744**
Total 12,300 million ECU			

Table 10.1: Breakdown of finances in the Fourth Framework Programme. Source CEC 1994.

The Brite/Euram programmes and their predecessors have always been an integrated part of all EU Framework programmes. Even though their strategic aims are influenced by the general guidelines and the spirit of the Framework programmes, they retain many unique strategic and implementation characteristics.

10.2: The BRITE/EURAM[2] Programmes

The European Commission's involvement in industrial and materials research goes back to 1985, since the early days of the first Framework Programmes with the design and implementation of "Brite", "Euram" and "Raw Materials and Recycling" programmes. Since the late 1980s, the three detached but overlapping and complementary programmes were merged gradually (see **Figure 10.1**) into the "Industrial and Materials Technologies – "Brite/Euram" programmes (currently *Brite/Euram IV*) aimed at the establishment and support of the necessary science and technological base for the development of new and advanced materials, S&P technologies, advanced manufacturing technologies, new products and industrial processes.

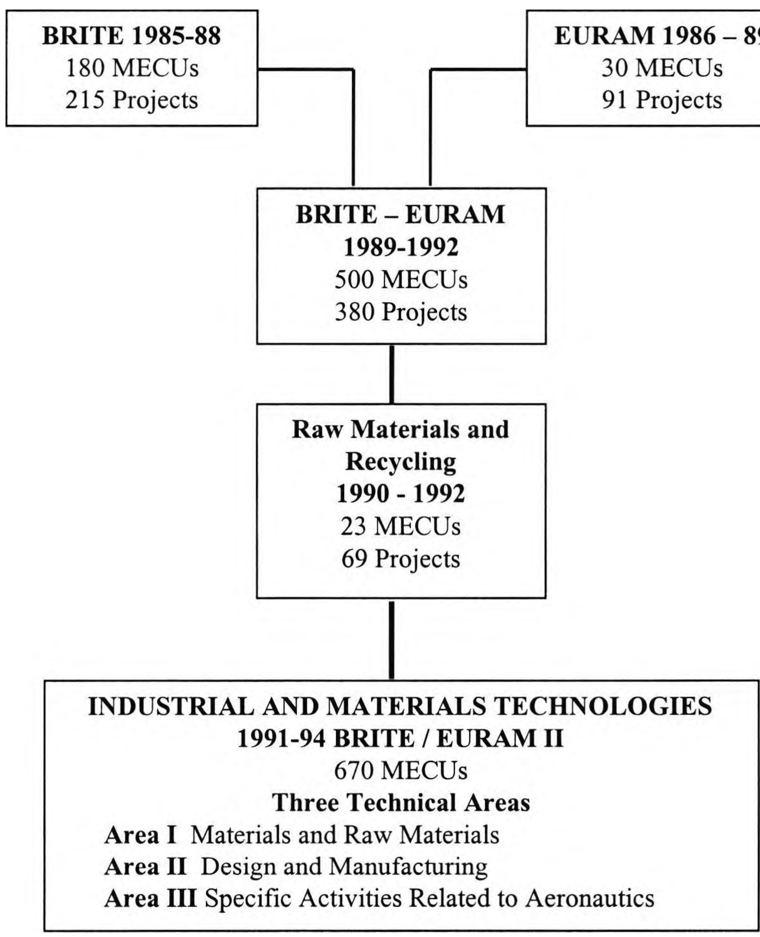

Figure 10.1: The Merging of Brite/Euram programmes. Source: CEC 1994.

[2] **Brite**: Basic Research in Industrial Technologies; **Euram**: European Strategic Research in Advanced Materials.

The first Brite/Euram programme (1989 – 1992) was implemented under the second framework programme and had a budget of 500 million ECUs. It was formed with the integration of the, then, separate Brite and Euram programmes (see Figure 10.1) and financed 380 R&D projects.

On 23 April 1990 the European Council adopted the Third Framework programme (see Annex 10.1) and one of the new activities in the field of Industrial and Materials Technologies was the *Brite / Euram II* programme (1991-1994) which emerged out of the integration of Brite/Euram I and the "Raw Materials and Recycling" programme with a total budget of approximately 670 million ECUs.

The basis of Brite/Euram II was the revitalisation of European manufacturing industry by reinforcing its scientific and technological base through R&D work in materials and industrial technologies. The programme was divided into three technical areas (see Figure 10.1) which placed greater emphasis on:

- A *systems approach* with multi-disciplinary teams;
- Co-operation between (materials) *producers, suppliers and users*;
- Pre-normative research;
- Working conditions and the environment;
- Participation of specific third countries (the, then, EFTA group).

A *key aspect* of the programme is the direct linking of materials R&D with processing and manufacturing technologies. Research was undertaken in the fields of raw materials, recycling, new and incremental materials, S&P technologies, design, manufacture and management of industrial operations with the following aims:

- improvement of technologies covering the entire life-cycle of materials and products;
- development of new, improved and advanced materials and their processing;
- incorporation of improved methodologies and techniques into design and manufacturing;
- reduction of design-to-product lead-time;
- improvement of cost effectiveness and management of manufacturing processes.

The *Brite / Euram III* (1994 - December 1998) programme, as a part of the fourth Framework Programme has a total budget of *1995* million ECUs including standards and testing measures, approximately 2.5 times higher than Brite/Euram II. Brite/Euram III follows the directions taken by Brite/Euram II, but puts greater emphasis on:

- Stimulating technological innovation.
- Promoting the incorporation of new materials, technologies and processes in traditional sectors as well as the emergence of new industrial activities.

- Promoting multi-sector and multi-disciplinary technologies for potential widespread applications.
- Promoting scientific and technological co-operation and integration in Europe.

As its predecessor, *Brite/Euram III* involves three technical areas spread over 21 research fields summarised with **Table 10.2.** Brite / Euram III also provides emphasis on standards and testing.

RESEARCH AREAS	Budget (in MECUs)
Area 1: PRODUCTION TECHNOLOGIES 1.1: Incorporation of new technologies into production systems 1.2: Development of clean production technologies 1.3: Rational management of raw materials 1.4: Safety and reliability of production systems 1.5: Human and organisational factors with in production systems.	**590**
Area 2: MATERIALS AND TECHNOLOGIES FOR PRODUCT INNOVATION 2.1: Materials Engineering 2.2: New Methodologies for product design and manufacture 2.3: Reliability and quality of materials and products 2.4: Technologies for recovering products at the end of their lifecycle	**566**
Area 3: TECHNOLOGIES FOR TRANSPORT MEANS **Area 3A: Aeronautics Technologies** 3A.1: Aircraft design and systems integration 3A.2: Aircraft production 3A.3: Technologies for improved aircraft efficiency 3A.4: Environmental technologies 3A.5: Technologies for aircraft safety 3A.6: Technologies for aircraft operation **Area 3B: Technologies for Surface Transport Means** 3B.1: Design of vehicles and systems integration 3B.2: Vehicle production 3B.3: Technologies to improve vehicle efficiency 3B.4: Environmental technologies 3B.5: Technologies for vehicle safety 3B.6: Technologies for vehicle operation.	**461***
STANDARDS AND TESTING	**288**

Table 10.2: Brite/Euram III – Research Areas. (Source CEC 1994).

* Half of the budget reserved for aeronautics and the other half for any other type of surface transport.

10.2.1: Common characteristics of the Brite/Euram programmes

As with many other EU advanced technology programmes, the participating companies in the Brite/Euram programmes are obliged to contribute at least 50% of the total project funding, with participation from at least two and preferably more than three EU member states. The European Commission funds up to a maximum of 50% of the research expenses of the project which can last from 24 to 48 months. Academic or other research organisations may opt for 100% funding of additional costs.

Allocation of resources is placed through calls for R&D proposals which compete within specific selection/evaluation criteria. The successful proposals secure financial support for 24-48 months.

The scope of the research work is broadly defined as *pre-commercial* and *pre-competitive*, but within Brite/Euram this definition has been elastically interpreted, and it is said not to have been a serious constraint on quality programmes put forward by researchers or companies (Farrands 1992, Bach et al. 1995, Interviews results 1996-1997). For example, in Brite/Euram III community funding does not normally exceed 50% of the projects budgets (100% for academic institutions - as in Brite/Euram II) but with the possibility of being further reduced if the project involves competitive research - a new regulation introduced for the first time in Brite/Euram programmes.

Emphasis is given on all four elements of the materials tetrahedron but S&P technologies, simulation and modelling, development of advanced materials and training issues are the most prominent areas.

The Brite/Euram programmes are regarded to be amongst the most successful of EU high technology programmes (Farrands 1992, Sharpe 1994, Bach et al. 1995, Bach, Cohendet and Ledoux 1995), partly because they have commanded widespread support without political controversy, partly because they have delivered many of their promises, and partly because they have attracted substantial interest from industries and individual firms anxious to participate.

10.2.2: Emerging trends in the Brite / Euram programmes

Brite/Euram III differs from its predecessors in many respects. It introduces many complementary innovations while some strategic transformations are gradually emerging affecting both the implementation of the programme *per se* and the role of participants (as well as the probability of them becoming participants). Based on information retrieved from EU data archives and on the opinions of interviewed experts[3] in Greece the following important changes have been identified:

1. The overall budget of Brite/Euram III is 2.5 times larger than its predecessor and the budget of individual projects became bigger[4]. As such, the new budget

[3] Many of these experts are participating in Brite/Euram programmes as both project co-ordinators or participants and as members of the Brite/Euram Steering Committees (decision making committees).

[4] The early Brite/ Euram individual projects were competing within an overall budget of approximately 1 million ECUs. A small research team (e.g. a University based research team) could

requirements welcome project proposals supported by large companies and R&D consortia and deter small research teams (e.g. university departments or laboratories) or isolated SMEs.

2. For the first time the submission of the project proposals must contain estimation (or even feasibility) studies with respect to the tangible implementation of R&D results. In practice, even the basic research proposals must include at least one industrial partner and at least one potential materials final user who will try to commercialise the R&D results. These changes enhance the role and the influence (during the project selection) of corporations (intensive materials users such as the automotive and the aerospace industry in particular) which are more applied research oriented and deters pure research participation (i.e. proposals supported only by research organisations) which were quite numerous in Brite/Euram I and II.

3. With respect to corporate participation, Brite/Euram III introduces for the first time targets on the basis of tight and very specific time horizons. The early Brite/Euram projects allowed a 3-4 year period to the participating companies before tangible evidence of complete or partial implementation of the project's R&D results took place. Brite/Euram III has reduced the implementation time to 1-2 years after R&D results become available. As such, companies with infrastructure and organisation imperfections have significant difficulties to prove that they can effectively respond to the new commercialisation time limits.

4. Due to the introduced innovations described above, Brite / Euram III became better organised and more target focused than its predecessors. Thus, the project selection mechanisms became more efficient and the evaluation criteria are applied with increased precision and accuracy. As such, proposals which do not fit precisely the programme's requirements are rejected[5].

5. Finally, there is an increasing tendency for the enforcement of an unofficial project pre-selection mechanism. Large, high technology companies such as the French AeroSpatial and the German Siemens and Deutsche Aerospace, who are usually among the major programme's contractors, and have formulated technology strategies and R&D portfolios, call research teams with which they are familiar (or all the research teams and smaller companies under their sphere of influence all over Europe) to submit research proposals in specific areas of interest. Then the large

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respond effectively with a proposal involving volume of work using 5% -10% of the total budget (50,000-100,000 ECUs). The Brite/Euram III individual projects are in a budget of approximately 5 million ECUs and it is very difficult for a small research team (or a SME) to effectively respond to the required volume of work corresponding to the same percentage (5%-10%) of the budget without substantial industrial support.

[5] While in the past a project proposal had to be simply relative to the programme's requirements.

corporations evaluate the "proposals" - or submitted ideas- according to the needs of their R&D portfolios and technology strategies and they allocate their preferences to ready and waiting research teams by submitting a joint proposal to the Brite / Euram project evaluation committees.

This tendency is a rather unpleasant development for research teams or SMEs who wish to stay independent or self-reliant and strengthens chapter's 4 findings that closer co-operation between large materials users and materials producers reshapes the relationships between them and SMEs and research institutions to a more demanding form of co-existence[6].

Moreover, the combined action of all the introduced innovations provides additional motives for the formation of long-term, complementary, technology-based alliances and integrated R&D networks replacing "loose" collaboration networks. Increasingly Brite/ Euram III acts just as a framework for stimulating international R&D and industrial co-operations without making significant financial contributions. Companies without academic links and academic or research institutions without corporate links would be expected to face increased difficulties to participate in Brite/Euram III and probably its successors.

In parallel with these developments, an unofficial but very rigorous debate has been established on what direction the future Brite/Euram programmes would take. According to the interviewed experts in Greece (RI1, RI2, TAC1, PAC2) there are primarily two schools of thought.

The first school of thought supports the "high technology" view and is mainly sponsored by Germany and France and Holland as it primarily reflects the needs of the high technology German and French industries. This stream of thought involves research and applications of very advanced technology and materials or new advanced materials for niche markets and very high technology applications (e.g. nuclear power stations, military and aerospace applications, advanced information technologies and telecommunication applications).

The second school of thought is endorsed by many EU countries and supports the concept of providing emphasis on medium-to-high technology priorities concentrating around incremental and advanced materials. The rationale behind this concept is that future Brite/Euram programmes should focus most of their attention on the needs and capabilities of industries which form the "**bread**" of EU. That is the low to medium

[6] Research teams and SMEs are gradually having less freedom of choice (or flexibility) with whom to co-operate. The emerging trend dictates that in order to secure long-term survival, research teams and SMEs in particular have to be at least "loosely" *aligned* with the needs or strategies of powerful national or international players.

technology intensity industries and services which account for approximately 70% of the industrial EU revenue (CSC 1994). That is commodity industries which can be revolutionised with the introduction and application of emerging materials technologies and new advanced processing techniques.

According to the information above, the evolution of the strategic aims and the changes of the application of Brite/Euram programmes reflect to a large extent the prevailing way of thinking, choices and strategic orientation in EU. On the other hand, the EU's materials strategic choices (as expressed mainly by the Brite/Euram programmes) affect the choices made by many European States as they can act as guide or reference points for the formation of their own national materials strategies, and thereby the opportunities and strategic considerations of domestic industry.

The introduced innovations in the implementation of the programmes impose new challenges to potential participants as they clearly favour some innovation systems (e.g. R&D clusters and large R&D consortia) and discourage some others (self- reliant systems). That can endanger the levels of participation of companies and research organisations based in member states with "incompatible" national innovation systems and thus it imposes an additional challenge on the design of the national materials and technology strategies.

10.3: Greece and International R&D Co-operation

Greece has a notable record of participation in international R&D collaborations. The Greek part takes the form of participation in international, world-wide research, bi-lateral co-operations and of participation in mainly EU sponsored R&D collaborative programmes or projects. In more detail:

International research publications. To begin with, Greece has a remarkable record of scientific linkages with international (word-wide) research. The extent of a country's links with other countries is reflected by the percentage of the total research publications which include researchers of other nations (OECD 1991). This indicator (mean percentage of eight research fields[7]) is presented in **Table 10.3** for each of the twenty OECD countries where statistically reliable data are available. For the 1976-1990 period Greece is steadily among the top ten of the OECD countries by steadily growing its participation in international, co-authored publications.

[7] Mathematics, Earth & Space, Physics, Biomedicine, Biology, Engineering & Technology, Chemistry, Clinical Medicine (OECD 1991).

This high internationally co-authored publications output is the academically tangible result of research collaborations motivated by a) inter-personal contacts of academic and researchers with common interests, b) the results of bi-lateral official collaborations and c) the results of participation in international R&D collaborations such as the Brite / Euram programmes.

	1976	1986	1990
Switzerland	20.7	32.3	37
Belgium	18.3	31.6	36.5
Austria	16.5	30.6	35
Ireland	17.7	29.6	34.5
Yugoslavia	20.7	31.6	34.5
Denmark	24.1	31.6	34
Norway	18.3	27.6	31
Greece	**14.4**	**25.4**	**30**
Sweden	16.3	26.4	30
Italy	16	26.7	29.5
France	11.3	23.4	28.5
Germany	11	23	28
Netherlands	16.5	24.3	27.5
Canada	14.3	22.5	26
Finland	17.8	23.3	25
United Kingdom	11.8	20.1	24
Spain	14.7	20.6	23
Australia	11.6	19.3	22.5
United States	6.5	12	14.5
Japan	4.9	9.5	11.5

Table 10.3: Internationally co-authored publications as a percentage (%) of a country's total publications (Source: OECD 1991).

Participation in EU R&D collaborative programmes. Greece has invariably achieved very high levels of participation in almost all EU R&D programmes in all four EU Framework Programmes. **Table 10.4** as adapted by Planet Ltd. (1994) provides an indicative summary of Greek participation in the most important EU R&D programmes classified on the basis of participation of companies, academic institutions and research institutions. For the 1985-1993 period alone Greece accounted for 795 participations in EU R&D collaborations. Most of these however, involved academic and research institutions (538 - 67.7%) rather than company participations (257 - 32.3%).

Greece is also active in peripheral EU programmes such as the EUREKA[8] initiative. Twenty-two companies and seventeen research institutions participate in 33 EUREKA projects. Greek participation is more intense in the laser, robotics and environment programmes. Moreover, the Mediterranean co-operative programmes are an additional area of international co-operation in Greece.

Programme	Firms	Research Institutes	Acedemic Institutes	Total
AERONAUTICS	3	0	15	18
AID FOR MARITIME NAVIGATION	0	3	0	3
AIM	6	4	5	15
BIOLOGY AND RADIATION PROTECTION	0	12	8	20
BIOTECHNOLOGY	0	3	5	8
BRIDGE	1	8	2	11
BRITE	10	7	9	26
BRITE-EURAM	36	16	26	78
CLIMATOLOGY	0	1	9	10
DELTA	8	1	2	11
DOSES	0	1	0	1
DRIVE	24	3	9	36
ÉCLAIR	1	0	2	3
ENERGY SAVING	4	0	1	5
ENERGY SYSTEMS & MODELS ANALYSIS	0	1	2	3
EOLIAN ENERGY	1	0	3	4
EPOC	3	0	16	19
ESPRIT	101	30	53	184
EURET	0	0	1	1
FAR	0	3	0	3
FAST	0	0	3	3
FLAIR	2	2	1	5
FOODSTUFFS TREATMENT	0	0	1	1
FUSION	0	1	1	2
GEOTHERMAL ENERGY	4	3	0	7

Table 10.4 continuous...

[8] EUREKA was launched in 1985 aiming to strengthen European competitiveness by facilitating co-operation in R&D of advanced technologies designed to compete on the world markets. Since June 1994 the Initiative numbers 23 members including the EU, the remaining countries of the EFTA group, Hungary, Russia, Turkey and the European Commission. A total of 12.5 billion ECU has been committed by companies, research institutes and governments for projects ongoing at February 1994. The EU framework research programmes and EUREKA are complementary programmes and a synergy between them is ensured through several common activities. Eureka mainly targets market-oriented research (hence the higher company participation) although some projects deal with more basic research problems.

Programme	Firms	Research Institutes	Acedemic Institutes	Total
HUMANGENOME	0	1	0	1
JOULE(B)	0	6	2	8
JOULE(E)	7	9	3	19
JOLUE(F)	2	4	4	10
JOULE(G)	1	1	1	3
JOULE(M)	0	1	1	2
JOULE(R)	1	2	7	10
LARGE SCALE FACILITY	0	1	0	1
MANAGEMENT AND STORAGE OF RADIOACTIVE WASTE	0	2	0	2
MAST	0	10	12	22
MEDICAL RESEARCH	0	1	1	2
NON-NUCLEAR ENERGY	0	2	2	4
PREPARATION OF NEW PROGRAMMES	0	1	0	1
PRIMARY RAW MATERIALS	11	15	10	36
PRODUCTION AND USE OF NEW VECTORS OF ENERGY	0	1	0	1
PROTECTION OF THE ENVIRONMENT	0	9	30	39
RACE	22	3	13	38
REWARD	1	0	1	2
SCIENCE	1	31	21	53
SOLAR ENERGY	3	3	10	13
SPES	0	0	2	2
STEP	2	3	20	25
STIMULATION	0	3	10	13
TELEMAN	0	1	1	2
WOOD	1	3	2	6
TOTAL	**257**	**215**	**323**	**795**

Table 10.4: Greek Particiaption in EU R&D programmes. (Source: Planet Ltd. 1994).

Bilateral co-operations. Greece has struck many agreements of inter-governmental bilateral research co-operation in fields with common interest with both EU and non-EU countries. The largest schemes are established with Germany and France but they mainly concern the involvement of academic or public research institutes. Industrial participation is very limited.

Materials research activities are involved in many bilateral co-operations addressing a very wide range of materials research fields and applications (mainly functional materials). Since the bilateral co-operations are dominated by the participation of research organisations, according to the findings of chapter 8 (see sections 8.2 and 8.3) this is an expected outcome. The Greek government, however, are wasting the opportunity to take advantage and use the bilateral collaborations as a powerful tool of technology and knowledge transfer in pre-selected materials (and other) fields.

Participation benefits. First of all, many of the Greek *horizontal* technology policy priorities (e.g. introduction of new technologies in traditional industrial sectors, support of human resources, promotion of international and national co-operation) and the mechanisms for their implementation (calls for research proposals - competition among the submitted proposals) have used as reference points or "raw" models the technology priorities and implementation mechanisms of the EU Framework Programmes.

With respect to economic returns, even though the research personnel in Greece measured in numbers of man-years is the lowest in EU, the Greek scientific and research community has achieved disproportionately high returns from participations in EU programmes. Up to 1994, and given that Greece accounts for only 1.25% of the EU population, 0.6% of its total R&D human resources and 0.3% per average of the total EU Gross Expenditure for R&D (in 1994 figures), Greece has managed to attract and implement approximately 3% of the total budget of the EU framework programmes reserved for R&D activities[9] (GSRT 1997).

The benefits of the participation are also demonstrated by a dramatic increase of the contribution of external (international) resources in the national Gross Domestic Expenditure for R&D. The contribution of incoming external resources in the national Gross Domestic Expenditure for R&D has been increased from 2% in 1984, to 12% in 1989 and 21.3% in 1993, placing Greece in the top position among the OECD countries with respect to the levels of incoming direct foreign investment for R&D activities. Therefore, the economic impact of the participation of Greece in EU R&D programmes (including Brite/Euram) can be considered as extremely important for modernising the national system of innovation and aligning it with EU standards (Planet 1994, Giannitsis 1995, Polyzakis 1995).

However, up to 1994, this remarkable record related primarily to academic and research institution participations while industry faced many difficulties in increasing its participation share (Planet 1994, Giannitsis 1995, GSRT 1996).

Most of the incoming financial resources were directed to significant improvements of the physical R&D infrastructure (e.g. new experimental equipment, new laboratory apparatus), which enhanced the competitiveness of the participants (universities/ research institutions) or to intangible but equally important benefits such as the creation or the enrichment of a critical mass of skilled human resources and the

[9] While the Greek contribution to the Fourth Framework's budget was 1.2%.

accumulation of R&D expertise in many high-technology fields including materials technologies (Planet 1994, Giannitsis 1995, Technical Chamber of Greece 1992).

Given the relatively low participation of Greek industry (final materials, systems and services users in particular) in R&D collaborations[10] and the existing weaknesses of the Greek national innovation system[11], there is wide-spread feeling in Greece that most of the R&D results are re-exported without making any significant, tangible impact to the Greek economy (Planet 1994, Giannitsis 1995, GSRT 1996).

Since the Brite/Euram programmes are among the most successful EU R&D programmes and given that Greece has a continuous and vigorous record of participation this issue is further investigated in the following section by the chapter's working hypothesis using the materials case as an indicative case-study but with wider and more general implications.

10.4: Greece and the Brite / Euram programmes

The analysis of the Greek participation in Brite / Euram programmes has a double aim:

1. to examine the level and the characteristics of the Greek participation through the evolution of the Brite/Euram programmes (testing of hypothesis H10.1), and,
2. to briefly examine if the Greek participation has any significant tangible impacts on the national system of innovation and the Greek economy (testing hypothesis H10.2).

Most of the following quantitative analysis is based on the 1989-1996 period because detailed and reliable data are available only for this period (provided by the National Documentation Centre in Athens). For the 1985-1990 period the available data are used with some reservation because they are derived from previous evaluation and consultancy reports and not from official Greek or EU sources. However, the figures used are regarded as good approximations. Moreover, during the data collection period (January 1997) participation figures in the Brite/Euram III were available only for the first call for proposals (until December 1996); nevertheless the existing evidence is sufficient to provide strong indications for the emerging trends because the quantitative findings are fully supported by the interviews findings where an

[10] The main reasons were reviewed and discussed in chapters 7 and 9.

[11] The lack for example of financial supporting mechanisms for the finance of technological innovation such as venture capital companies, company "incubator" mechanisms etc.

invariably unanimous opinion was expressed by all the interviewed participants (academics, research institutions, companies).

10.4.1: Analysis of the level of Greek Participation (Testing of Hypothesis **H10.1**).

During the 1984-1991 period the total number of projects including Greek participation in Brite/Euram programmes and its predecessors[12] was *162* projects out of which *63* projects (38.8%) included industrial participation and *99* projects (61.2%) involved academic and research institution participation (Planet 1994).

During the 1990-1996 period the total number of projects including Greek participation in Brite/Euram programmes was *149* projects out of which *65* projects (43.6%) included industrial participation and 112 projects involved academic and research institution participation. **Tables 10.5** and **Figures 10.2,3,4,** provide a more detailed picture of the Greek participation in the Brite/Euram programmes.

Based on the evidenced provided by Table 10.5 and Figures 10.2,3,4,5 and by looking into the details of individual programmes (too many to be summarised in a Ph.D thesis), the following findings can be derived:

The Greek participation in Brite/Euram programmes was steadily rising and reached its zenith with Brite/ Euram II with participations in 79 projects out of which 19 had Greek co-ordinators (primary contractors). The introduction of Brite/Euram III, however, marked a turning point and **the total number** of Greek participations **is falling** (both in terms of total numbers of company and research organisations participations and per average call of proposals - see Table 10.5 and Figure 10.3,4).

However, it is notable that the number of projects with **share of industrial** participation is **increasing** (from 33% in 1990-1992 to 64% in 1994-1996) while the number of projects with share of research organisations participation (and the total number of participating research organisations) is falling, lowering the total number of projects with Greek participation from 81% of the projects in 1991-1994 to 61% of the projects in 1994-1996 (see Table 10.5 and Figures 10.3,4).

An additional worrying trend, despite the increasing percentage of industrial participation, is that the **spectrum** of the participating industries and research organisations **is shrinking.** As shown in **Table 10.6** and **Figure 10.5** there are some

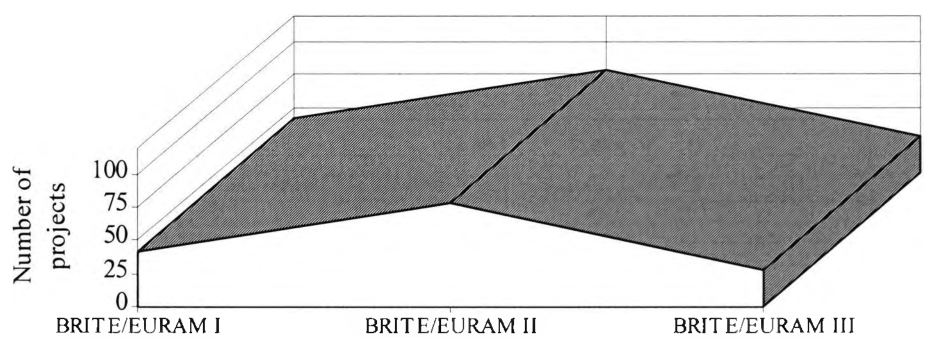
[12] The figures include participations in the Brite, Euram, Brite/Euram I, Raw materials and Recycling and the first call of proposals of Brite/Euram II programmes (see also figure 10.1).

notable variations in the materials field distribution[13] of the Greek participation in the Brite/Euram programmes over the 1990-1996 period.

BRITE/EURAM (1990-1996)	(III)* 1994-1996	(II)** 1991-1994	(I)*** 1990-1992
Total number of projects including Greek participation	28	79	42
Projects with Industrial participation	18 (64%)	33 (42%)	14 (33%)
Total number of participating firms	23	48[14]	17
Projects with research organisation✦ Participation	17 (61%)	64 (81%)	31 (74%)
Total number of participating research organisations	19	74[15]	37
Total number of projects with Greek co-ordinator	1	19	6
Total number of projects with a Greek firm acting as project co-ordinator	1	7	4
Total number of projects with a Greek research organisation acting as project co-ordinator	-	12	2

Table 10.5: The Greek participation in BRITE / EURAM programmes over the 1990-1996 period - four calls of proposals. The Table includes both completed and under execution projects. Source: Author from data provided by the NDC (January 1997).
* First call for proposals (1994-1996); ** Two calls for proposals (1991-1994); *** Second call for proposals (1990-1992); ✦ University department or research/technological institution.

Figure 10.2: Total number of projects including Greek Participation



[13] As classified in Table A8.1.
[14] Twenty-four (24) per call of proposals.
[15] Thirty-seven (37) per call of proposals.

Participation in:

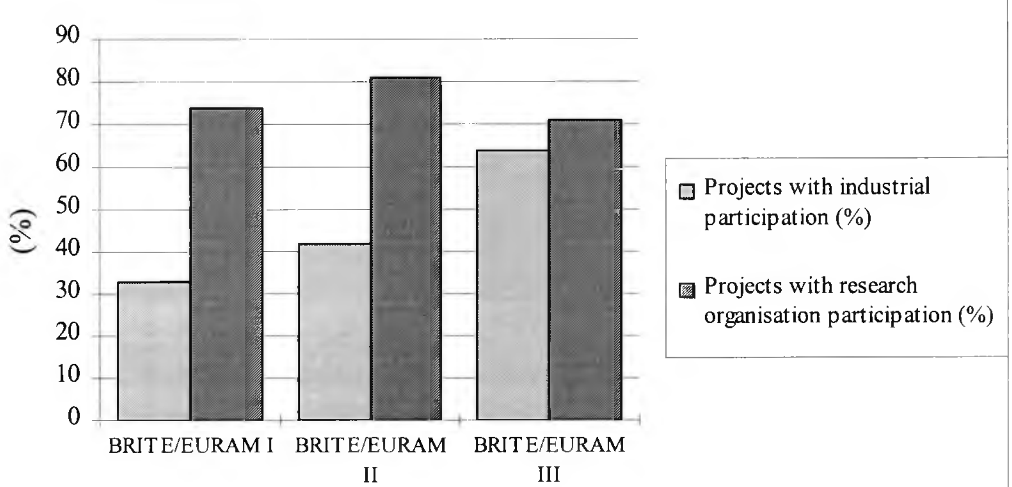
- class (11) simulation and modelling, design and S&P technologies is *on the increase,*
- class (6) recycling, chemical technologies, plastics and petroleum technologies is *marginally reduced*,
- classes (1), (2), (3) and (4) raw materials, mining technologies basic metals, commodity ceramics and cement technologies *is falling* (collectively)
- class (7) advanced functional and structural materials *is rapidly falling.*

These trends can be explained by looking into the special characteristics of the Greek participations and the innovation introduced by the Brite/Euram III (see section 10.2.2).

Materials field[16]	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
BRITE/EURAM III	3	2	-	1	1	5	3	1	-	-	10	2
BRITE/EURAM II	16	4	2	4	4	16	12	-	5	-	12	4
BRITE/EURAM I	-	5	1	2	3	6	11	-	-	-	10	4

Table 10.6: Materials field distribution of the Greek participation in BRITE / EURAM programmes (1990-1996). The figures cover both completed and under execution projects. Source: Author from "raw" data provided by the NDC (January 1997).

Figure 10.3: Number of Brite/Euram projects which include Greek participation (1990-1996)



[16] According to the classification of Table A8.1 in Annex 8.1.

Figure 10.4: Number of Brite/Euram projects which include Greek industrial and research participation (1985-1996).
Source: Author from data provided by Planet 1994 and NDC 1997.

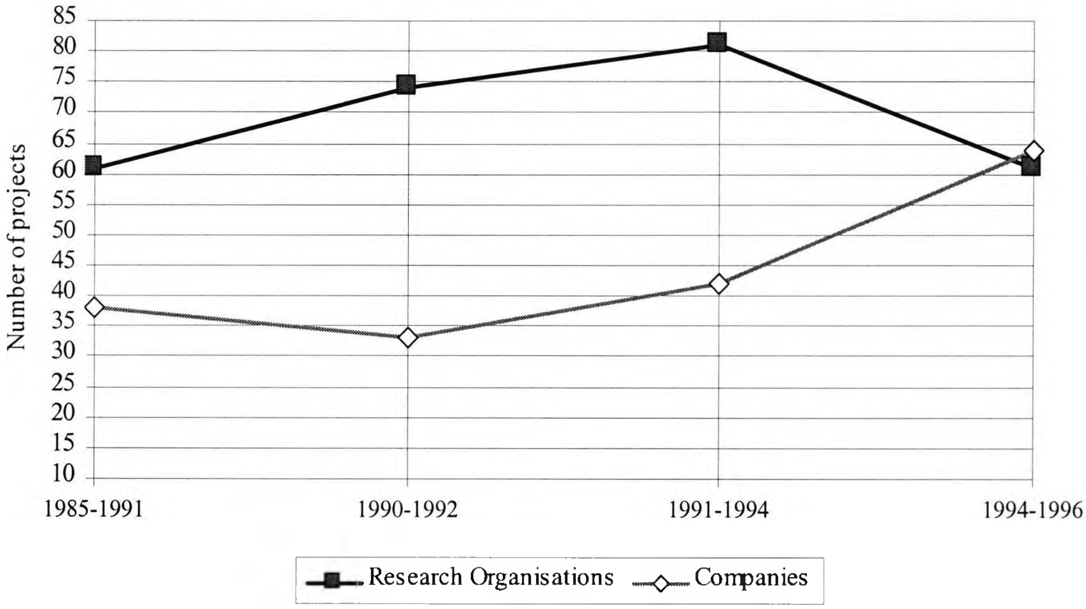
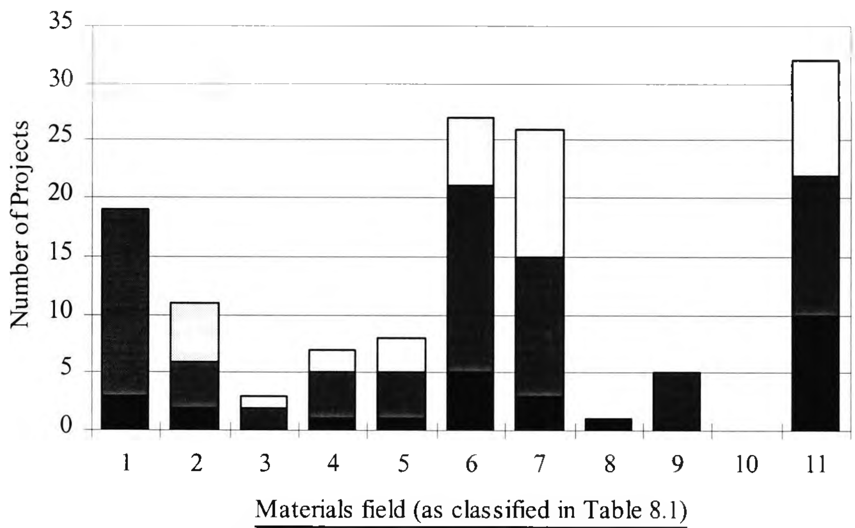


Figure 10.5: Materials Field distribution of the Greek participation in BRITE/EURAM programmes (1990-1996). Source: Table 10.6 data.



Decline of research organisations participation. Prior to 1994, given the relatively low initial R&D capabilities of the majority of Greek industry (see Chapter 7, Annex 7.1 and chapter 9), Greek participations were dominated by university and research institutions participations because the average level of the required technological and scientific standards was prohibitive for the average Greek company (including the large ones). On the other hand, small research teams located in various public research institutions (including universities) took advantage of the "open" character of the early Brite/Euram programmes which favoured and supported even pure research projects, and given their contacts and their accumulated research expertise (also see: the special role of the academics in chapter 8) they managed to be highly competitive over a long period of time.

This type of participation, however, inherited all the positive and negative characteristics of small research teams[17]. Moreover, in many cases, the initial motive behind a proposal submission was circumstantial (to secure funds or to simply financially survive as in many cases of university divisions or laboratories) and not the result of a wider strategic planing or as a part of a well-defined R&D consortium. That created additional consistency problems despite the isolated benefits.

Given the notable changes introduced with the application of Brite/Euram III (e.g. industrial project pre-selection, large projects, requirements for industrial participation, moving from units-based competition into R&D consortia based competition), the self-reliant Greek research teams find it increasingly difficult to keep pace with the new developments due to both size and structural limitations. As such, *the overall participation of Greek research organisations is falling.*

Increase of industrial participation. On the other hand, the percentage of projects with industrial participation follows the opposite trend. During the early Brite/Euram stages industrial participation was concentrated on low to medium technology intensity projects (with the exception of the telecommunications sector and many SMEs specialised in IT applications and modelling and design) involving manufacturing and S&P improvements or gradual improvements of incremental structural materials. Given the very low level R&D activities they had to heavily rely on common participations with research organisations, but as identified in chapters 7 and 8, links with them during the 1980s and early 1990s were very weak. However, given the long-term application of the national R&D programmes and the gradually

[17] Flexible and adaptable to a variety of circumstance but self-reliant and usually rotating around one or two powerful personalities (i.e. a professor or an experienced researcher) with limited capabilities of undertaking large scale projects with large budgets.

increasing participation in international programmes together with selected academic and other research teams, industries (notably in the ceramics, cement, non-ferrous metals, defence and telecommunications sectors) gradually improved their technological performance which enabled them to participate in Brite/Euram III on equal competitive terms. It is also notable than many Greek companies have formed un-official but stable integrated R&D consortia with specific research organisations or academic divisions (e.g. the relationship between Intracom S.A. and the Democritus research institution) and always compete with joint projects proposals which are frequently successful because they fit the new requirements imposed by the Brite/Euram III programme. Similarly, a considerable number of Greek academic divisions have managed to be fully integrated to the "sphere of influence" of large European companies and thus secured good possibilities for participation in future projects.

Spectrum of participation. According to the finding of chapter 8, advanced materials R&D activities take place primarily in universities and research organisations. As such, the rapid decrease in class (7) is generated by the decline of the total numbers of participating research and academic institutions in Brite/Euram III. This tendency has the potential to create a surplus of highly qualified and skilled human resources *with no object or occupation.*

On the other hand, the increase of participation in class (11) is mainly supported by a rapidly growing number of SMEs participations specialised in the delivery of high-quality, low cost simulation and modelling and other information technology related services to the EU materials and manufacturing sector. As expert PS2 pointed out, "*EU acknowledges the high-quality, low-cost, information technology services of Greece and they regularly employ Greek software expertise for any kind of problem or project*". This is an important technology asset in other small countries such as Israel and Taiwan. In Greece, the Greek government have officially recognised this national strength only since January 1998, but no specific measures yet exist aiming to exploit the existing strengths.

The reasons behind the marginally declining trend in classes (1), (2), (3), (4) and (6) are more complex. The Greek participation in these fields is dominated by industrial participations of large companies, regularly supported by a more-or-less stable group of research and academic teams. As such, the small decline of the Greek participation in these fields is the result of the combined action of a number of changes imposed by the implementation of Brite/Euram III and of Greek endogenous factors. As PAC2 and THAC1 pointed out, the early Brite/Euram projects allowed a 3-4 year period to the participating companies before tangible evidence of complete or partial implementation of the project's R&D results took place. Within these time limits, Greek companies, despite their management, technological and R&D weaknesses, had some reasonable chance to meet the imposed requirements. But Brite/Euram III has reduced the implementation time to 1-2 years after R&D results become available. Moreover, the project proposals have become very complex and multi-levelled calling for proposals managers and liaisons offices which many Greek companies do not have. As such, many Greek companies wishing to act as the R&D results final users, due to infrastructure and organisational imperfections discussed in chapters 7-9, fail to respond (or to prove that they can effectively respond) to the new commercialisation time limits.

However, chapter 9 proved that a small but steadily growing number of Greek companies (notably in the ceramics, cement, defence and non-ferrous metals sectors) have managed to take advantage of their early participation history and their links with universities and research institutions, are constantly improving their technological performance, and they have formed a "critical mass" of large companies with constant presence in Brite/Euram projects.

10.4.2: Analysis of the benefits of participation (Testing of Hypothesis H10.2).

The preceding analysis brings forward the question of whether Greek participation in the Brite/Euram programmes has produced significant tangible impacts on the national system of innovation, the MSE field in Greece and the Greek economy.

Tangible benefits. Apart from general economic and administrative benefits (see section 10.3), the tangible benefits for the Greek national innovation system and the MSE field in particular, are reflected in the creation of high quality physical R&D infrastructure in many research institutions and academic departments.

As most of the interviewed experts pointed out, thereby verifying the findings of older studies (i.e. Planet 1994, Giannitsis 1995, GSRT 1996), many public and private MSE laboratories were equipped with high technology laboratory equipment and experimental machinery and apparatus (which become an asset of each laboratory) through participation in Brite/Euram programmes. Given that until 1994, most of governmental expenditure in the MSE field focused on chemistry and chemical processes related technologies, participation in the Brite/Euram programmes provided a balance in the creation of a "critical mass" of high standards MSE laboratories (most of them certified with ISO 9001 and moving to obtain the EN45000 certificate) active in the structural and incremental materials fields.

However, as chapter 2 identified, MSE laboratory equipment is among the most expensive and requires constant updating in order to be able to deliver cutting edge, competitive research. Given the decline of the participation of Greek research teams (and hence laboratories) in the Brite/Euram programmes, if a long-term participation interruption takes place, and no other financial sources are secured, then the research value of the existing laboratory apparatus will rapidly decline. **This is a crucial finding of this research and merits both private and governmental consideration.**

Commenting on the *tangible benefits* of the participation in Brite/Euram programmes for the Greek national economy, two evaluation reports (Planet 1994 and Giannitsis 1995) concluded that these benefits are almost insignificant and all the generated R&D results and added value is re-exported without been commercialised in Greece.

In view of the preceding evidence and according to the opinions of the interviewed experts, this conclusion *is inaccurate.* The analysis of the previous evaluation reports was primarily based on pre-1990s participations which were dominated by research participations, and many projects involved pure research and no Greek industrial partner to act as the R&D results final user and thus commercialise the results. Moreover, these reports did not proceed in analysing the Greek participation in Brite/Euram on the basis of materials fields and they derived their conclusions on the basis of mean averages without identifying emerging tendencies and trends. As the interviewed experts identified the picture is very different:

Expert PS2 pointed out that many of the results of projects involving IT, CAD/CAM and simulation and modelling applications - class (11) - are exploited by Greek companies either directly or indirectly as spin-offs, simply because they are needed. Similarly, projects involving incremental S&P improvements in fields (1), (2), (3), (4) and (6) also stay in Greece because the Greek industrial base has a compatible technological level and can efficiently exploit them. Under the same specifications, projects involving the improvement of structural materials (or incremental materials in general) provide results compatible with the capabilities of many Greek industries and they are also exploited by them. However, these achievements are not publicised and thus a distorted picture emerges.

For very advanced technology applications however, most of the produced output is re-exported and implemented by non-Greek companies. As experts PAC1, PAC4 and PAC8, suggested this is largely the case in field (7) (advanced structural and functional materials such as Carbon-Carbon Composites, superconductors, advanced memory devices, light alloys for aerospace applications etc.), in field (5) (many cases of very advanced surface treatments) and in approximately half the cases of field (6) (chemical processes, catalysis, advanced high temperature applications, etc.), simply because there are no Greek firms able to implement these technologies. But as PAC8 identified, even though the largest part of the research results in these materials fields is re-exported and exploited by EU firms, it is a very meaningful activity both in terms of EU integration and indirectly in terms of accumulated knowledge, skills and profits for the Greek economy. Given the projects' revenue, the acquired laboratory equipment and the accumulated expertise in terms of human resources, the Greek economy is always gaining. Moreover, the created human resources can be used in future diversification and technology fusion efforts across the EU; the entire EU benefits, and this is one of the aims of the horizontal R&D programmes of the Union.

Intangible benefits. The intangible benefits of the participation in Brite/Euram programmes for the Greek national innovation system and the MSE field in particular are invariably similar to the benefits obtained from international participation in any other technological field. The participations have created some international "centres of excellence" and a "pool" of high quality research teams with considerable research capabilities and expertise, able to deliver high quality research results at very competitive prices (see next section). Especially in the MSE field, it is the participation in the Brite/Euram programmes which has created a "critical mass" of highly trained human resources in many materials scientific and technological areas (e.g. semiconductors, advanced materials for electronic applications, advanced structural composites for aerospace applications, advanced light alloys etc). Yet, these benefits and achievements are fragile. Given that:

- many of these small research teams have been created out of the initiative of individuals (usually an experienced academic or researcher with good international links) and not as the outcome of a general institutionalised strategic plan,
- many of these research teams depend for their survival on future participations,
- the overall participation of Greece in Brite / Euram is falling and that mostly affects public research organisations,
- the domestic R&D markets are moving asymmetrically and with slower rates to cover the gap (there is a growing interest in fields (1), (2), (3), (4), (6) and (11) but not in (5) and (7))

there is an emerging issue of crucial strategic importance: what to do with all this surplus of high quality researchers accumulating tacit knowledge in high technology areas and how can it be efficiently deployed in Greece. This point receives further attention in the form of policy recommendations presented in chapter 12.

10.5: Conclusions

According to the findings of the preceding discussion, **the hypothesis H10.1** (levels of participation) **is rejected**. The preceding analysis demonstrated that the research organisations participation is rapidly declining (mainly due to new participation specifications) while industrial participation is steadily but slowly increasing in a narrow spectrum of materials fields. Hence, the overall Greek participation in Brite/Euram programmes is declining. This trend is the outcome of the combined effect of Greek institutional weakness and policy and implementation innovations introduced by Brite/Euram III and the Fourth Framework Programme.

The second **hypothesis (hypothesis H10.2) has been confirmed**. The tangible results of the Greek participation in the Brite/Euram programmes are directly related with the type and the nature of the participants. Participations deprived the involvement of Greek industrial units provide poor tangible returns. Participation involving Greek industrial units as the R&D results final users provide substantial tangible results.

At the present technological state of Greek industry, the R&D results of projects involving medium to medium-high technological applications in "traditional" industries can be **sufficiently commercialised in Greece** and re-exported as finished products. The R&D results of projects involving very advanced, critical or emerging technology applications for high-technology industries can not yet be sufficiently commercialised in Greece because there is no domestic industry to exploit them. As such, R&D results produced by Greek academic and research institutions **are re-exported** in the form of **high-value added R&D services**. However, even this process has provided spillover effects in the domestic research community.

These findings and conclusions contradict the findings of previous studies (i.e. Planet 1994, Giannitsis 1995) which argued that the *tangible benefits* of the participation in Brite/Euram programmes for the Greek national economy, are almost insignificant and all the generated R&D results and added value is invariably re-exported without been commercialised in Greece.

In addition, there are some significant policy implications for Greece. The findings of chapter 10 reveal a set of both specific and general character issues with wider technology policy implications for Greece. Given that:

- Until 1994 there was no national materials policy to provide some abstract but specific thematic directions or points of reference, the Greek participation in Brite/Euram programmes was entirely driven by the interests of private initiative, that might be a company, an academic, an experienced researcher or a small research team,

- Up to 1996, the Greek national technology policies did not provide any special considerations or arrangements in order to support[18] or co-ordinate this participation,
- The ongoing strategic and implementation changes in Brite/Euram programmes, and,
- The rapid decline of the scientific Greek participation, which creates a surplus of high quality researchers in high technology areas and erodes the capabilities of the physical R&D infrastructure,

the Greek government cannot persist on the same "*laisser-faire*" attitude without risking further severe reduction in Greek participation in all EU R&D collaborative projects with detrimental effects for the national innovation system and the Greek economy. Policy recommendations appear in chapter 12.

Finally, the findings of chapter 10 reveal a set of issues with wider technology policy implications. Given that the Greek case can be similar to other cases of small-to-medium EU countries with similar participation characteristics (e.g. Portugal, Ireland, Spain) and similar innovation systems weaknesses a set of issues emerges:

First there is the issue participation in EU Framework Programmes. What are the choices and the benefits for small to medium size European countries with weaknesses and gaps in their national innovation system (especially in emerging technologies) and weak finance mechanisms. The preceding evidence strongly suggests that some innovation systems are increasingly finding it more difficult to keep pace with the emerging Framework Programme trends. Therefore, it is recommended that a governmental strategy considers measures for attracting Foreign Direct Investment for R&D, supports and sponsors participation in EU programmes, pursues the formation of international links and gradually **changes** the institutional mechanisms of the national system of innovation.

Finally there is a policy issue for the EU. The EU must address the decline and marginalisation of countries with weak innovation systems and design policies which will enable these countries to participate and even specialise in specific fields.

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[18] On the contrary many bureaucratic problems were acting as a brake on the individuals' efforts to participate in Brite / Euram and other EU programmes. For example, legislation incompatibilities such as the issue of VAT for R&D activities in Greece have caused considerable problems for many participants.

Supplementary Note: In December 1998, the basic directions of the Fifth EU Framework programme were announced. The European Community has recognised the danger for the marginalisation or the decline of significant segments of its scientific base and has re-introduced the possibility to successfully submit project proposals supported only by research organisations. According to the above analysis it is expected that the Greek participation will significantly increase through an increased level of academic and research organisations participation. Moreover, the European Community provides more emphasis to emerging technologies for commodity and every-day life applications which create the "bread" of EU. That creates additional opportunities for successful Greek industrial participation.

CHAPTER 11: Conclusions, Contributions and Opportunities for Further Research

11.0: Introduction

Chapter 11 includes three sections. Section 11.1 presents the most important (key) findings and conclusions of the thesis with respect to the central hypothesis and research issues put forward in chapter 1. The central finding is that the concepts comprising the international materials "codes of practice" as an integrated conceptual whole cannot be compromised even in the case of economies under transition with weak national innovation systems and / or in the case of industrial sectors/companies operating within environments with these characteristics. Major institutional changes have to occur first in order to implement successfully the "codes of practice" and optimise their potential. The section ends with a set of additional findings and observations, which relate to the central conclusion of the thesis. Section 11.2 is a brief presentation of the contributions and originality of the present research. The thesis has uncovered and built new knowledge in the field, verified previous results, and identified new research frontiers. Section 11.3 briefly presents a set of opportunities for future research and discusses the generalisation value of the findings and the methods of the present research. The section argues that the present research is particularly useful for economies and national innovation systems which are dominated by public sector activities and/or were commercially isolated (until recently) from direct international competition (arguably the East European and Balkan countries).

11.1: Findings and Conclusions

Given the working hypotheses and the detailed analysis in chapters 7-10, the aim of Section 11.1 in not to repeat all the detailed findings and conclusions of the thesis, Section 11.1 focuses only on selected key results and conclusions.

The central issue of the present thesis is the question of under what conditions can firms, industries and national economies take advantage of the opportunities offered by the materials revolution and remain competitive in a fast changing, technology - intensive, competitive environment. The thesis argued that this aim is achievable if MSE strategies and capabilities are integrated with technology and business strategies on the basis of a minimum set of universally accepted "*codes of practice*". The key elements are summarised in **Table 11.1** and they are reflected in the employed questionnaires. The "codes of practice" are contained in detail and fully developed and analysed in chapters 2-6.

Table 11.1: The International "Codes of Practice" as defined from chapters 2-6

I. The Technological Level: Affects Both Corporate and National Level
• What lies at the core of the MSE field and the MR and what provides an underlying coherence to this diverse field is the materials tetrahedron (Figure 2.1), the four basic materials elements – Performance, Properties, Structure and Composition and Synthesis and Processing – and the relationships and interactions among them as an integrated whole. • Once a new target is set or a major scientific breakthrough occurs, all the four basic elements of the materials tetrahedron must necessarily be involved if a successful result is to be achieved. Particular attention must be provided to materials performance (the connecting link of the MSE field with design, human needs and the market place) and Synthesis and Processing (the connecting link of the MSE field with the manufacturing floor and *the basis of using* materials and materials technologies as *enabling generic tools* in order to achieve multiple targets). • Materials R&D activities must simultaneously encompass all four elements of the materials tetrahedron. As the US NRC (1989) put it: '*If MSE is to remain healthy and productive, R&D addressing all four elements of the field and their interrelationships is vital*'. Neglect of one of the four materials elements (and particularly of the S&P) can result not only in materials policy but also in technology policy failure with all the consequences that might have. • MSE R&D activities necessitate the employment of advanced computer power and modelling and simulation skills. General modelling and analysis skills applied throughout the organisation are of equal importance because the MSE field is gradually evolving into a fully quantitative field. According to the UK technology foresight panels (DTI 1995) gaining skills in the area is a capability which can not be externally acquired. • The regular updating, replacement or acquisition of new equipment (experimental apparatus) and funding for R&D in new equipment (both experimental apparatus and industrial machinery) is crucial for keeping materials research and production capabilities at the cutting edge. • Information diffusion mechanisms, compatible data and standards and testing and measurement methods are crucial for materials R&D progress and for materials R&D commercialisation. Corporations can only promote the adoption of commonly accepted standards and measurements while the establishment of information diffusion mechanisms and internationally accepted standards is in the domain of national policies, national innovation systems and international collaboration. • Well-trained human resources in all four materials elements, at both graduate and postgraduate level, is one of the most important infrastructure aspect for MSE R&D and materials strategies. Creating a critical mass of highly trained and skilled personnel in materials technologies is identified as a priority for human resources at corporate level and a national educational priority at national level. • The multidisciplinary nature of the MSE field and the complexity of its interactions with other technologies, processes and product design, the manufacturing floor and the business environment necessitates multi-disciplinary approaches within the firm and externally which usually take the form of long-term, technology-based alliances and collaborations between corporations and/or between public and private sector organisations (e.g. between universities and corporations). • Materials technologies require the existence of a strong organisational structure and supporting infrastructure at both corporate and national level. Materials R&D necessitates the involvement of the entire corporate innovation system at corporate level and the national innovation system at national level.

- There are two main but interrelated and complementary technological trajectories in materials strategies: the strategy which aims to improve existing materials and optimise the way they are employed and the strategy which aims to create new materials with new properties and functions and therefore create new products and possibly technologies. An integrated MSE strategy serves business objectives better when it keeps the balance and calls for simultaneous action on both materials technological trajectories.
- Materials R&D and materials strategies are of necessity long – term in nature. Given that the R&D effort has to be integrated into successive short, medium and long-term product development (see also Level II – corporate / industrial level) materials R&D portfolios and strategies have to comprise both the improvement of incremental materials and processes and the development of new materials. Within this framework, seven to ten years time span is not an unusual requirement for new materials development R&D projects. Time periods for different development stages can vary from case to case but adding all stages together results in a long time period. Short-term R&D efforts alone have an adverse effect on both corporate and national capabilities in drawing and effectively implementing materials strategies which comprise both the improvement of existing materials and processes and the development of new materials and technologies.
- The implementation of structural or functional materials R&D activities includes notable variations, but the basic R&D principles originating from the materials tetrahedron remain unchanged. The argument gains crucial importance in the case where R&D and materials strategies are tailored to specific business objectives subjected to tight budgets or time-tables.
- Given that materials R&D and materials strategies are *de facto* a long-term issue, both at corporate and national level, they necessitate long-term and uninterrupted availability of financial resources.

II. The Second Level: Corporate / Industrial Level

- At corporate level, materials strategies must be fully integrated (or at least directly connected) with the technology, manufacturing and business strategies of the corporation. When this task is achieved materials competencies can become the foundation of rejuvenation strategies, technological and business diversification strategies and the origins of technology fusion strategies. To achieve this integration and optimise its results a corporation must:
  - Employ Kaizen and Simultaneous Engineering management tools and practices
  - Have organised R&D departments and well-defined materials R&D portfolios.
  - Integrate the materials R&D portfolio to corporate R&D.
  - Employ a third generation R&D approach which is regarded as the most suitable for materials R&D.
  - Have a balanced materials R&D portfolio able to address all three materials R&D stages, that is basic research, applied research, near-market research.
  - Combine learning-by-doing with learning-by-interacting practices.
  - Be able to form and manage links with research/technological organisations and governmental agencies.
  - Be able to form and manage collaborations and complementary strategic technology alliances (e.g. between materials producers and users).
  - Be able to identify, manage and efficiently protect materials and other technological core competencies over time.
  - Have already developed a number of in-house capabilities such as simulation and modelling, reverse engineering and technological information and evaluation skills.
  - Have the ability to combine strategic management controls (ideal for designing and implementing long-term materials and technology strategies) with financial controls (to ensure operational effectiveness).
  - Employ senior management able to distinguish between corporate and technology strategy and strategies for operational effectiveness. Moreover, senior management able to combine technology/science, management and finance principles is more likely to be more successful in achieving the above tasks.

III. The Third Level: National Level
• At national level, national materials strategies must be integrated with (or at least tailored to meet the needs of) national technology strategies and priorities and if possible act in support of national industrial strategies. Within this framework the role of the government in designing and implementing a national materials strategy is three-fold: ♦ Identify national materials priorities according to the needs of national technology and industrial policy, the size of the economy, and the capabilities of the national system of innovation. ♦ Provide a favourable environment for the development and diffusion of national and private materials strategies. This would include: – The provision or support of national research infrastructure (e.g. research /technological institutions, governmental laboratories, universities, public agencies, technological information diffusion agencies) in support of materials and other science/technology activities. – The national research infrastructure, as an integrated part of the national system of innovation, must be able to address and support the national materials priorities in co-operation with private sector. – Given that a significant part of national materials (and technology) strategies is implemented through the national system of innovation, a basic but complementary R&D "division of labour" must exist among the distinctive elements of the national research infrastructure (e.g. role of governmental laboratories, universities, technological institutions etc). – The provision and support of appropriate graduate and postgraduate education and continuous education schemes targeting MSE principles (S&P in particular) and 'holistic' management perceptions. – The provision of data bases, standards and standardisation mechanisms addressing both materials development/production and final utilisation. For the commercialisation of new materials or technologies based on new/advanced materials in particular, the provision of standardisation mechanisms is more effective than the provision and protection of patents. – The provision mechanisms supporting the finance (allocation of resources) of long-term technological innovation. – Horizontal measures (e.g. tax incentives for R&D) create a favourable environment for R&D but they can not effectively support specific technologies or technological fields. They must be augmented by product or technology specific measures such as long-term loans, product procurements and long-term market securitisation schemes (particularly effective in the materials case). – Given that financial markets have the tendency to discriminate against materials-based technological innovation and SMEs, government must provide risk capital and mechanisms for its allocation to strategically important technological fields and SMEs. ♦ Design and provide the appropriate mechanisms and initiatives for the implementation of the national materials strategies and priorities through the national innovation system. The selected initiatives and the applied mechanisms (e.g. national R&D collaborative schemes) must: – Provide a balanced support for all four elements of the materials tetrahedron and for the development of generic skills (i.e. mathematical and simulation and modelling skills) in the national research, education and R&D infrastructure. – Include both mission and application oriented R&D projects and provide support to both pre-competitive and applied materials research. – Target specific technological/materials fields or groups of technologies. For small countries with limited capabilities, the most suitable approach is to target enabling groups of technologies/materials tailored to meet complementary needs of pre-selected industrial sectors. – Be able to build upon and augment existing (horizontal) strengths. – Address or support the needs of both materials users and producers. – Promote collaborative approaches and the formation of industrial and R&D links and networks. – Include monitoring, supervision, feed-back and continuous improvement mechanisms.

Table 11.1: The International "Codes of Practice" as defined from chapters 2-6

The central Hypothesis of the thesis addressed the critical question of how and to what extent relatively small industrialising nations or economies under transition (and important segments of industry) with weak R&D tradition, technology infrastructure, and/or weak industrial or institutional structure, can effectively respond to the onset of the challenge imposed by the Materials Revolution.

> The ***Central Hypothesis (H1)*** of the thesis is that in these cases, **either** the international "codes of practice" have to be modified first before being applied to each industrial sector and /or national level **or** a significant structural and institutional change has to occur first.

The thesis first identified the "codes of practice", classified them into three distinctive but inter-related levels and used them to examine the response of the Greek private sector (selected industrial sectors) and public sector. The most important findings and conclusions are as follows.

11.1.1: The private response: private materials strategies

Materials producers: Cement, refractories, consumer/commodity ceramics producers, non-ferrous metals and non-ferrous metallic products producers, ferrous metals producers (after 1992).

The preceding empirical chapters demonstrated that there are considerable materials strategy variations and differentiation among the reviewed industrial sectors. The cement, the consumer/commodity ceramics, the non-ferrous metals producers and M2 have identified MSE competencies as a basic foundation for competitive advantage and, inspired by international experience, they have developed multi-level materials strategies as an integrated part of their technology, business and operational strategies.

The ceramics sector, M2 and to a lesser extent the non-ferrous metals sector have adopted all or most of the international "codes of practices" and they implemented them according to their needs and operational environments. In more detail:

- They have developed materials R&D activities as an integrated part of their R&D portfolio.
- Their materials related R&D addresses all four elements of the materials tetrahedron providing particular emphasis on the element of S&P.
- They have adopted a flexible, third generation type of R&D organisation structure.

- They have developed and manage both technological and commercial core competencies (most of them materials related).
- They support their technological and materials activities with a set of in-house supportive competencies (e.g. simulation and modelling skills, human resources policies, etc.).
- They have adopted Kaizen and SE management practices and they apply them both on their production floor and during the design and implementation of their R&D portfolio and product development.
- They have developed extensive technological links, interactions and collaborations (with the exception of M5) with the national research infrastructure (e.g. universities and research institutions) and their machinery or materials suppliers (all sectors). Nevertheless, they have not yet developed extensive complementary alliances with the final domestic users of their products mainly due to the inability or the lack of interest of these sectors to respond.

Ferrous Metals and Materials Users: The defence industry, the construction industry, the case of M1 and some ferrous metals producers (before 1992).

Contrary to the ceramic and non-ferrous metals materials producers, segments of the ferrous metals sector and the reviewed final materials users (the defence sector, including shipbuilding, and the construction sector) reveal a totally different picture: **The defence sector** appears to be **technologically compromised** and its response to the materials revolution appears to be **rather patchy** as it perceives materials competencies only as a supportive element of its activities, not as fundamental competency. In more detail:

- The sector has developed R&D activities but their R&D portfolio is clearly designed to serve short to medium term production and manufacturing needs and technology transfers.
- Materials related research (if any) is directly connected with these priorities.
- S&P related R&D has primarily the mission to smooth the integration of advanced but internationally established materials in existing products or production capabilities, not to support the development of new products as an outcome of in-house materials competencies.
- In most cases, materials (and other) R&D activities are subjected to strong financial limitations as the companies do not have the capability to allocate

adequate resources to R&D despite their connection (and operational subsidisation) by the Greek State.

- Major segments of the sector appear to be isolated from the national research infrastructure; moreover, a lack of communication between the Ministry of Development and GSRT was identified.
- Apart from the case of MU1, the sector has not developed strong technological ties with its materials suppliers.
- The sector is subjected to strong external influences the analysis of which lies outside the domain of the present research.

On the other hand, **the construction sector** (the most intensive materials user of materials produced in Greece) is a rather unique case. The companies of the sector operate under conditions of high uncertainty and they appear to be **technologically unprepared** to develop sophisticated materials strategies as a direct result of their operational and organisational structure. In more detail:

- Only large and /or specialised construction companies have developed corporate structures and only a handful of large and/or specialised companies have addressed the issue of management of technology as an integrated part of their operational activities and not as a circumstantial issue.
- Their basic technological aim is to be "intelligent technology and materials users", a task achieved by exceptionally strong competencies in the processes of learning-by-doing and especially learning-by- interacting through direct human interaction.
- The sector is fully aware of the technological and commercial potential of advanced materials and materials technologies and is open to technological and materials innovation when cost considerations justify it.
- The companies of the sector however, (even the large ones) put emphasis on processing (in situ S&P) rather than the material per se. As such, the sector has not developed complex technology and materials strategies and does not possess sophisticated materials R&D capabilities.
- Only very large companies or the large specialised companies are en-route to developing corporate technology strategies (as defined in chapters2-5) and R&D capabilities (including materials activities).
- The sector has not developed strong technological ties with materials producers, and,
- The sector is under-supported by the national R&D infrastructure and by standards policies and arrangements, suffers from a lack of communication with GSRT and

the Ministry of Development and has been practically omitted from participation in the national R&D collaborative schemes.

The above evidence illustrates that most of the reviewed *materials producers* have developed materials strategies in co-ordination with their technology and business objectives or in response to the characteristics of their operational environment. That illustrates that the international "codes of practice", as defined in chapters 2-6, **can be successfully adopted and applied** even in the case of industrial sectors or corporations operating within weak national innovation systems or in environments significantly different from those where the "codes of practice" have been formulated.

A set of issues arise however, in relation to the basic materials directions *per se* adopted by the reviewed Greek companies and sectors. When it comes to materials R&D, apart from C2, all the other companies focus their attention exclusively on the improvement of incremental structural materials for mainstream commodity applications. Only C2 has developed an extensive R&D programme targeting the development and commercialisation of *globally new*[1] structural materials for mainstream applications as a corner-stone of its diversification activities and only C4 has allocated resources in functional ceramics R&D as a "diversification experiment". No materials based technology fusion efforts were identified. According to the findings of chapter 2, this is the most conservative approach able to sustain or provide competencies only for the immediate or medium term future. As both chapter 2 identified, and, C2 verified, this approach involves long-term risks as it limits business opportunities (e.g. entry into emerging markets) and can ultimately compromise in-house technological capabilities.

With respect to the reviewed *materials users*, the above evidence indicates that both the construction and the defence sector have not realised their potential as strategic materials users and they have not extensively capitalised on in-house materials competencies.

The **defence sector** has the necessary structures and technological capabilities to adopt and successfully implement the international "codes of practice". However, for reasons beyond the domain of the present research (see below - opportunities for further research) it fails to adopt or successfully support and implement a considerable number of them. As such, if in the future the Greek defence sector aims to strengthen its competitiveness, and hence national defence, through in-house materials

[1] C2, does aim to introduce new materials in, say , Greek or EU markets. C2 aims to develop totally new materials and introduce them in global markets.

competencies **considerable internal institutional changes have to occur first** mainly affecting the operational and decision making structure of the sector.

On the other hand, the **construction sector** has developed remarkable expertise in the utilisation of new or advanced but established materials and has *just started* (in technological terms) to develop corporate materials strategies as a response to competition intensification. But before the sector proceeds to more complex stages, **major** organisational and internal **institutional changes (at corporate level)** have to occur first.

11.1.2: The national response: public materials strategies

The preceding empirical chapters demonstrated that the Greek contemporary national materials strategies -or priorities- are still in an embryonic stage. The first materials technological priorities have been identified only since 1994 but they have not yet been effectively supported by a set of specialised measures tailored to the requirements and characteristics of the MSE field. The support they receive from the national technological infrastructure and the way they are implemented through the existing institutional arrangements and mechanisms of the national innovation system, are *indistinguishable* from any other technological field or general national policy priority. The special requirements and characteristics of the MSE field are not taken into consideration. Hence, it would be more accurate to speak about national materials activities and priorities rather than a fully formulated national materials strategy directly subjected to the merits and shortcomings of the existing national innovation system. In more detail:

<u>A) Priorities identification:</u>

** The identified national materials priorities (summarised in section 8.2) provide emphasis on incremental and advanced structural materials of primarily metallic and ceramic nature for mainstream consumer applications. They also include a narrow range of advanced functional materials (mainly of ceramic nature) and structural composites for specialised applications. These priorities are (in principle) in accordance with the existing domestic research capabilities and contemporary Greek industrial basis.

** The identification of the existing materials priorities includes the element of complementarity as the selected directions address common needs and capabilities of both materials producers and users (e.g. construction industry).

** The selected materials priorities reflect a **conservative approach** as they primarily support -through materials competencies- the rejuvenation of mature industries and the elevation of low-technology industrial sectors to an "intelligent technology users" status via new or improved products rather than new technologies. In addition, the concept of materials technologies based diversification or technology fusion has not yet been sufficiently addressed by the national materials priorities.

B) Implementation:

The implementation and support of the national materials priorities takes place through existing mechanisms designed to deliver horizontal priorities and/or satisfy the prevailing market forces (see section 7.6: comments on the implementation of the national R&D collaborative schemes). Given that these mechanisms have reached their efficiency limits, it is exactly this implementation which:

- Has practically excluded the participation of major industrial sectors directly related to the national materials priorities (e.g. construction sector).
- Has failed to address and support the materials users-producers relationship.
- Has inhibited the formation of strong industrial networks.
- Is in the process of marginalising materials (and other fields) pre-competitive research.
- Has created project supervision and evaluation problems.

Moreover, a number of additional negative developments have been identified:

1) Absence of centrally co-ordinated, large scale mission-oriented pre-competitive materials R&D projects.
2) Serious gaps in the supporting research and technological infrastructure, such as the limited capabilities of the existing materials-dedicated research institutions, and the lack of research infrastructure dedicated to materials applications such as construction technologies.
3) Failure to use public contracts and market securitisation techniques as a primary force of new technology development.
4) Lack of supporting education policies (e.g. scholarships, continuous education, technical education), and fully developed standards policies tailored to materials needs or to materials applications needs.
5) Lack of State capital for technological innovation outside the framework of the national collaborative schemes.

According to the above it is evident that the implementation (and up to a certain extent the design) of the national materials activities and priorities are **constrained** within the accomplishments and limitations of the Greek national innovation system as it has been shaped during the last 15 years of re-design and re-definition.

Successful **concepts** ("codes of practice") **are continuously derived from international experience** (especially during the design and definition stage of the national materials priorities); **paradigms of their implementation, however, are not**. Moreover, the national innovation system and its mechanisms do not include any differentiations which take into account the special characteristics and requirements of each technological field.

The materials case has illustrated that the present institutional arrangements and mechanisms **have reached their effectiveness ceilings** and since they are left unsupported by specialised, technology-tailored actions, they have the potential to create more long-term shortcomings than benefits. As such, the national materials priorities and activities **are expected to have a limited tangible impact** focused on isolated large firms or small clusters of firms.

In addition, Greece has taken the decision to identify and pursue a limited set of very conservative, low-to-medium technology intensity materials priorities. This is justified because the present circumstances and arrangements of the national innovation system **are unable to efficiently support** an aggressive and multileveled materials strategy targeting the development of new materials and advanced materials technologies or other materials-related emerging technologies. Therefore, if Greece aims to strengthen the effectiveness of the existing national materials priorities and then develop and effectively support a multi-level national materials strategy - not just the identification of a set of conservative priorities- **considerable additional institutional changes have to occur first (**or take place **simultaneously** with the development of the national materials strategy).

In conclusion, the directions and choices of a national materials strategy are defined by the national needs and characteristics but probably above all, by the **kind of vision** the policy makers have for the nation and the development of the national economy.

11.1.3: Technological innovation and financial markets

The materials case demonstrated that the Greek financial markets do not efficiently support technological innovation. The Greek banks, despite their historical expertise in supporting industrial development, have failed or avoided to address the issue of financing technological innovation, mainly due to internal weaknesses such as lack of internal expertise and lack of analysis and evaluation mechanisms. They provide support only on the basis of corporate size and credibility.

Venture capital on the other hand, is still weak and modelled on European prototypes rather than USA prototypes. The Greek venture capital companies do not discriminate between technological fields and they provide emphasis on low-to-medium risk investments such as expansions of established firms, not start-ups or high-risk investments. As such, R&D spin-offs, commercialisation of university research and high-tech SMEs suffer the most.

On the other hand, the Greek State does not provide sufficient compensation for these market imperfections. The investment law acts as a form of long-term loan for industrial development rather than an instrument for the financing of technological innovation. Moreover, its implementation (very similar to the implementation of the national R&D collaborative schemes) has, in practice, excluded entire industrial sectors such as the construction or the textiles sector. In addition, the Greek State has failed to use technology specific financial incentives such as procurements and market securitisation for materials and other similar technologies. As such, technologies requiring large and long-term capital investment (such as materials technologies) suffer the most.

11.1.4: Central hypothesis conclusion

The combination of all the above evidence and findings leads to the conclusion that:

1) **"Codes of Practice"**. At *corporate level*, the international "codes of practice", **can be universally and successfully adopted and applied** even in the case of industrial sectors or corporations operating within weak national innovation systems or in environments (institutional frameworks) significantly different from those where the "codes of practice" have been formulated. At *national level*, the international "codes of practice" *per se* **are relevant as a coherent whole at the conceptual level**, even in the case of transition economies with weak R&D

infrastructure or institutional arrangements as in the case of Greece. The problem becomes one of policies and institutional mechanisms for supporting them and implementing them.

The only case where small modifications of some of the international 'codes of practice' is possibly necessary is the case of the construction industry. At this stage we conjecture that this may be the case because:

-- the construction sector provides more emphasis to the process rather than the materials *per se* and,

-- its characteristics and operational conditions are significantly different from materials production and/or manufacturing industries (from which the corporate "codes of practice" have been extracted),

Further research is clearly required here.

2) **Institutional Framework**. The materials case has illustrated that both at corporate and national level the development of complex and sophisticated materials strategies and the *implementation* of the international 'codes of practice' *must be supported by an appropriate institutional framework* supporting both their development and implementation.

3) **Designing and implementing next stage sophisticated materials strategies within the Greek national system of innovation**.

- The examination of the Greek national system of innovation has demonstrated that at both the sectoral and national levels, which clearly interact at several points, the present Greek institutional arrangements and mechanisms for the design and implementation of materials strategies **may have reached their limits** in terms of effectiveness.

- Our findings lead to the observation that the reviewed industrial sectors (bearing in mind the findings under (1) above) which operate within the Greek national system of innovation and experience its various weaknesses, would have difficulty in moving towards and implementing more complex and sophisticated stages in materials technology strategies. That is, we would expect that sector-wide, intersectoral and national-level **organisational and institutional changes** would need to occur prior to or simultaneously with the development of such strategies in the future.

- Our findings have wider implications regarding the role of major organisational and institutional changes prior to the development and application of multi-level, long-term materials strategies for industrial sectors and corporations operating within national innovations systems and especially in the case of transition economies with weak R&D infrastructure or institutional arrangements in Southern European Union economies, and elsewhere.

- Careful consideration and future research is required to examine the reasons for the success (or failure) of specific industrial sectors within weak national systems of innovation and the pre-conditions for successful, long-term materials strategies.

11.1.5: Additional findings, conclusions and observations

The analysis and results point to several additional findings and conclusions of significance, which are discussed in detail in chapters 7-10. Below, section 11.1.5 lists a number of key conclusions and findings emerging out of the combination of the preceding empirical and theoretical evidence.

Private Sector

Corporate materials R&D portfolio. All companies provide almost exclusive emphasis on incremental structural materials. With a few exceptions, there is no balance between structural and functional materials or between incremental and new materials as identified in chapters 2 and 3. R&D in advanced structural materials and functional materials still remains within universities and research/technological institutions and, as chapter 10 pointed out, the Greek industrial base is unable or unprepared to exploit the results.

Materials and corporate/industrial sector competitiveness. The findings of the NRC report on Advanced materials for the 1990s[2] (NRC 1989) have been **confirmed**. The NRC study demonstrated the close relationship between long-term commercial performance of industrial sectors/companies and their materials competencies. The industrial sectors which have developed materials competencies as a response to competition intensification sustain or even expand their market shares. Those who didn't suffered from serious losses. All the reviewed sectors and case studies of the present research provided an one-to-one verification of this relationship[3]. The thesis also demonstrated that this relationship can be safely expanded in the case of monopolies and individual companies / corporations.

Management of technology issues. The findings of the present research **contradict** the findings of Tsipouri's study (1993) on research and technology management in

[2] See section 3.5.

[3] Apart from the construction sector which due to its particular nature is profitable without substantial materials competencies.

enterprises[4]. The findings of Tsipouri's study indicated that Greek enterprises manage technology either by coincidence or by immediate reward (net present value). Apart from the majority of the construction sector (not the large specialised companies) which verifies these arguments, the materials case *contradicts* Tsipouri's findings.

Most of the reviewed companies have developed technology and materials strategies as an integrated part of their business portfolio or in response to the characteristics of their operational environment, they tailor their R&D activities after their operational needs, they have identified core competencies and they employ (consciously or by implication) Kaizen management techniques. Nevertheless, for some sectors environmental influence has worked as an initiative for competitive advantage, while for some others (notably the materials users oriented to serve domestic markets) it has become an inhibitor of technological and materials development. Focus on short to medium term projects, lack of vision, and more importantly, objective internal or external limitations inhibit the effectiveness of the employed practices.

A typical example of the argument is the case of financing R&D activities: while R&D is identified as a strategic competence, many companies still finance it using the net present value rule, even though they know that this is not the best possible practice. Given the focus on short to medium term projects this approach is probably acceptable. *However,* the short to medium term R&D horizons do not allow the development of three stage R&D models and limit the rewards of the adopted third generation R&D models.

Materials strategies and corporate size. The findings demonstrated that in the case of companies operating within weak national innovation systems size is paramount as companies have to provide internal organisational and resources compensations for the system's shortcomings.

International exposure. The level of international exposure of each sector / company is a major source of materials and technology strategy differentiation. The higher the level of international exposure (in terms of targeted markets or ownership) the more sophisticated and mature the corporate materials and technology strategies.

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[4]Tsipouri, L. (1993): '*Research and Technology Management in Enterprises: Issues for Community Policy: Case Study on Greece.*' Monitor / Sast activity: Strategic analysis in Science and Technology. CEC (1993), EUR - 15436 - EN.

Public Sector

The role of Universities/Research institutions. According to the findings of chapter 8, public research organisations hold a key role in the Greek national system of innovation. In many materials fields, Greece still remains in pace with international developments mainly due to the contribution of its public research organisations. Under the present arrangements, however, the Greek research institutions have reached their contribution limits. To proceed to the next stages, a number of additional institutional changes are required.

National Systems of Innovation and Materials. Kingery (1991), Nelson (1993), Nelson and Rosenberg (1993), Lundvall (1992) and Pavitt (1971 and 1996) suggested that some national systems of innovation offer comparative and competitive advantage for the nucleation, development and diffusion of technological innovation. In the materials case, the findings of the present research, when combined with the findings of Hane (1992) and Lastres (1993), *verify* the argument. Moreover, they strongly suggest that some national innovation systems and their institutional arrangements have a comparative advantage to cope with and efficiently support materials-related technological innovation. Note the similarity between Kaounides and Chelsom's arguments that at corporate level, some management tools and practices offer comparative and competitive advantages in developing complex materials strategies and successfully integrating them into corporate technology and business strategies.

Common Topics

Corporate and national S&P capabilities. The internal structure and the operational conditions of all the reviewed companies and the two technological institutions have favoured the development of strong S&P capabilities. In addition the implementation and the priorities of the national R&D collaborative schemes provide emphasis on and support to S&P issues. Only university-related research is aligned with international experience as it provides emphasis to properties and structure and composition, not S&P (for reasons explained in detail in chapter 8). The developed S&P capabilities however, are limited to existing and incremental materials and products. With a few exceptions, it is questionable if they can cope with the development of entirely new products or if they can provide the necessary support to the development and commercialisation of advanced or globally new materials.

R&D activities and pre-competitive research capabilities. All the reviewed companies (including the cement companies) underlined that they provide emphasis to near market research or applied research tailored to specific problems. The longest-recorded duration of individual projects was four years. Given that the national R&D

collaborative schemes also promote near market or applied research (and guide universities and research/technological institutions in this direction) it is questionable if Greece will be able to sustain pre-competitive research capabilities in the near future.

11.2: Contributions

There are no major studies (particularly at Ph.D. level) dedicated to materials strategies as connected with Greek corporate technology strategies and the Greek national system of innovation[5]. The present research is the first major study in Greece, which takes a wholistic, all-around approach, examines the views of all the involved parties, attempts to identify core technological needs shared by many sectors and analyses their strategic implications for operational competitiveness. Further, in order to achieve its central goal (verification or contradiction of the central hypothesis), the thesis has developed and verified the key hypothesis by providing analysis, insights and findings on a number of issues. In more detail the thesis:

- Thoroughly investigates the Greek national response to the MR challenge.
- Provides an extensive analysis of the interactions between materials strategies and the Greek national system of innovation.
- By employing the materials case as an analytical case study, (the thesis) provides extensive analysis and insights on numerous technology policy issues such as technology policy implementation mechanisms and selection of priorities.
- Provides insights and findings on the selection and implementation of materials strategies and on the implementation of the national R&D collaborative schemes.
- It is the first study which argues that the present arrangements of the national innovation system (especially the allocation of R&D resources) discriminates against important industrial sectors (materials users in particular) and it is the first study to identify 'hidden' shortcomings of the Greek innovation system (e.g.

[5] Even the Technology Foresight studies dedicated to metals, ceramics, construction materials, polymers, energy and transport strongly focus on market or technical feasibility issues rather than on strategic analysis of materials issues as connected with corporate technology strategies and the characteristics of the national system of innovation. These studies provide useful information on present and near future technological trends (which technologies / materials are expected to be deployed in Greece by the year 2000 and 2010) but they do not make extensive technology strategy recommendations. Most of them do not connect materials issues with business / technology strategy issues and operational competitiveness and they do not identify the necessary pre-requisites, institutional arrangements and management requirements for the design and implementation of corporate or national materials strategies.

erosion of domestic skills for pre-competitive R&D) crucial for the implementation of a complex and multi-levelled materials strategy.

- Provides insights on the role of Greek academia and research institutions for the development and implementation of national materials strategies and identifies strengths and weaknesses of the existing higher education system with respect to MSE principles.
- Is the first to study standards and standardisation issues with advanced materials issues in Greece and provide comments and ideas with wider implications.

Moreover, the thesis provides insights on:

- The Greek private response to the MR challenge,
- Technology strategy and management of corporations in Greece,
- The application and implementation of Kaizen and SE practices in Greece,
- The extent of links and collaborations formed by Greek companies within the national system of innovation,
- The response and the character of Greek financial markets with respect to the provision of capital (investment) in technological innovation (similarities and differences with EU and USA models of action are also identified).

In addition,

- The thesis is the first study that brings forward and analyses the participation of Greece in Brite/Euram programmes, identifies and analyses trends and makes strategic recommendations for improvement.
- Even though the key aim of the present research was to develop and test the central and subsidiary hypothesis as discussed in chapters 1-11, the thesis makes an additional contribution by the provision of a set of private and national materials policy recommendations which follow directly from the insights, evidence and findings of the thesis for the case of Greece (see chapter 12).

According to the above, the results of the present thesis are expected to make a significant contribution to the development of appropriate contemporary and future public and private materials strategies in Greece.

- Since Greece does not have a fully formulated and deployed materials strategy at present (only materials priorities have been identified), the findings of the present research are expected to make a major contribution to the formation and deployment of a fully formulated national materials strategy on the basis of recorded international experience.
- Participating companies in the private sector have expressed a strong interest to be kept informed of the results of the present study. In fact, the results of the present

study have been requested by almost all the participants in both the public and private sector.

In addition to the above, the study makes a number of contributions of wider (general) interest. In more detail:

- The thesis is the first academic work which not only identifies frontier developments in MSE and the strategic responses of firms, industries and governments world-wide, but synthesises and organises them into a set of "codes of practice" (or experimental apparatus/analytical tool) which can be employed to evaluate any materials strategy at any level.
- The thesis is the first study to use extensively the relationship between materials users and materials producers as major analytical instrument.
- The "codes of practice" and the results can be employed as a technology strategy reference point for the operation of research institutions, companies, banks and venture capital companies, professional associations, governmental agencies and university laboratories related to MSE and other similar technologies.
- The present study has verified results of previous studies (e.g. the NRC report on materials technologies and competitiveness), it has supplemented or expanded the results of other studies, and it has contradicted some of the results of some other studies (focusing on technology issues in Greece).
- The identification of the internationally "accepted codes of practice" provided the opportunity for a *synthesis* of existing works and ideas usually supported by well established theoretical backgrounds. Thus, the investigation of the interactions taking place among materials issues and organisational, management of technology, innovation and other issues *provided vivid illustrations and strong verification examples* of well established academic theories and management practices such as the non-linear innovation model, market failure and the role of the government, systems management and engineering, R&D and technology management, Kaizen management principles, learning-by-interacting, complementary alliances and others.
- Most of the ideas/theories employed during the first part of the present study are not original *per se* although *some conclusions* coming out of the *synthesis* of these ideas with the materials field *are original and contribute* to the understanding of the MSE field and its implications for technological and business competitiveness.

Finally the study makes two additional small contributions by:

- Identifying a number of challenging opportunities for further research (see below), and,
- Providing a detailed presentation of the Methodology of the present research (Annex 1.1). Apart from the necessary justification of the selected mode of action

Annex 1.1 includes *a detailed presentation of the small but essential practical details* (the nitty-gritty details) of the selected methodology. These practical and time consuming details are usually omitted from similar studies. Nevertheless, they are not trivia – they are time consuming and they are essential for the quality and the validity of research.

11.3: Opportunities For Further Research

The following opportunities for further research were identified:

1) Materials strategies as evaluation 'tools' of technological status. Given that:

-- materials and MSE technologies are enabling technologies, and hence, the level of technological development is directly connected with the materials sophistication level, and,

-- given that materials technologies and strategies require for their successful implementation high and sophisticated levels of supporting facilities and organisational / management structures,

an investigation, analysis *and above all evaluation* of the status of these technologies can provide a very good approximation and indication of the overall technological level and technological / R&D capabilities of a corporation, industrial sector and/or national innovation system.

This concept was brought forward as a suggestion at the end of chapter 5. The empirical parts of the present research provided very strong indications that the assumption is correct. Hence a challenging opportunity for further research is a project attempting to verify the *hypothesis* that the status of sophistication of materials technologies and strategies is a good indication of the overall technological status of a corporation, industrial sector or even nation.

Under the same notion, the materials "codes of practice", and methods of action for the development and implementation of materials strategies can be used as pilot or reference cases for the design and implementation of technology strategies or for strategies targeting the creation of infrastructures and institutional mechanisms.

2) Internal balances of power and materials (technology) strategies. As PS4 (1997) pointed out, the level of technological development of a country is directly connected with the local socio-economic structures and characteristics. Therefore, the alteration or eradication of factors inhibiting technological development *possibly* requires a direct conflict with all the established elements which formulated the established

technological conditions as well as with an *ad hoc* redesign of policies and choices. The empirical chapters verified these views especially in *the case of public enterprises* which appear to be either technologically compromised (apart from few exceptions) or unprepared to respond to the emerging challenges despite their in-house capabilities (e.g. size and internal structures) and the efforts of the Greek State to initiate and support corporate R&D activities. PAC3 and PAC6 pointed out that this paradox is directly related to internal structures and perceptions reflecting internal networks and balances of power. The argument was also put forward or indirectly implied by a number of experts such as PS4, PS1, VAC1, AAC1, VC3, C3, M1 and PAC9[6].

Hence, a challenging area for future research is to investigate the influence of power networks and the internal distribution of power in the formation and implementation of corporate and national materials and technology strategies and in the characteristics of the national system of innovation.

3) Application of the materials principles in the IT and the Biotechnologies fields.

The first question to be investigated is to what extent the same or similar methodology approaches can be applied in the IT and the Biotechnology fields. That is, to what extent internationally accepted codes of practice can be identified, and which organisational and management arrangements are suitable to support technology strategies in these two fields. The second question is to what extent principles, paradigms and practices developed for materials technologies can be transferred or applied as reference points to IT and Biotechnologies.

A suggestion is that information technologies can be approached with the same methodologies and materials principles can be applied in their case because both materials and IT are enabling technologies and, additionally, the two fields are tightly inter-connected. With biotechnology however, caution is recommended. Biotechnologies are not yet enabling technologies while the entire field is strongly subjected to external influences related to issues of life, morals and ethics.

4) The materials "codes of practice" and the construction field. The review of the Greek construction industry demonstrated that the sector provides more emphasis to processing rather than the materials *per se*. In addition, the construction industry has many unique characteristics related either to its operational environment or to objective factors such as slow pace of change. Given that the corporate materials "codes of practice" are derived mainly from manufacturing companies or materials producers, chapter 9 identified the possibility for some "codes of practice" modifications tailored to the unique characteristics of the construction sector.

[6] Note the distribution of the experts: they cover all the participating parties (e.g. public servants, companies, venture capital companies, universities etc.)

5) Materials and theoretical issues. The materials case has provided strong indications that the (well established) academic theories employed by the thesis and management practices are compatible and complementary in many different levels and perspectives. By using materials as illustration paradigms further theoretical synthesis of established ideas can be carried out in order to create a manual of universal guidelines and recommendations. Individual areas can also benefit. The Alcoa-Audi alliance for example, demonstrates that large materials producers and large final materials users come closer to each other in pursuit of complementary technological and business objectives. Is this a general trend applied to all materials related fields or to any technology - related field? And if it is what are the implications for networks and alliances and what are the new roles for intermediate companies and high-technology SMEs?

6) Materials and cultural/social influences. The impact of cultural differences in the design and implementation of materials strategies (technology strategies in a wider perspective) has been insufficiently investigated[7]. There is great potential for further research in this field.

11.4: Generalisations

The thesis provided evidence that in the case of Greece, many of the existing corporate MSE strategy problems trace their origins to public materials and technology policy problems and the national innovation system's shortcomings. Some large companies have developed internal mechanisms in order to compensate lack of public support. SMEs however, can not afford to act on a similar way. That has a direct impact on economies dominated by SMEs. Typical are the economies of Greece, Spain, and Portugal. Hence, the technology policy and infrastructure recommendations of the thesis can also be applied in other Southern Europe countries.

In addition, the Greek case has many similarities with many ex-communist East European countries:

As in Greece, economic competitiveness depends in large part on the ability of the region to manage technology for manufacturing exports (Weiss 1993). There is an inflated role/participation of the public sector in the national economy and the internal structures it has created. As in Greece where many industrial sectors were traditionally

[7] There is only one extensive study dedicated to the subject: Kingery, D. (ed.) (1991): '*Japanese / American Technological Innovation: The influence of cultural differences on Japanese and American innovation in Advanced Materials*. Elsevier Science Publishing Company, NY.

oriented to satisfy internal markets, most East European output was oriented toward civilian and military needs of the former Soviet Union, and cannot now be sold anywhere. The communist system of central planning and soft budgets provided no real incentive to efficiently manage technology, while technological innovation was hampered by isolation from changes in world markets and technology, and by the separation of research, and production. Moreover, Eastern European scientific and technological infrastructure is old-fashioned and under-equipped, but includes a strong nucleus which could be reformed and reoriented towards world markets (Weiss 1993) (something that Greece has done successfully but not yet on an organised basis). This process is beginning in several countries. But public support is lacking, as are funds for long-range investments in technology based projects (as in the case of Greece).

Hence, given these similarities, many of the findings and recommendations of the present study can find application to East Europe or Balkan countries. On a more general note, the findings and recommendations of the present study can find application in any economy with similar characteristics.

In conclusion Greece is an economy under transition. Given the extensive privatisation projects, the role of the public sector in the Greek economy may soon be significantly restricted. It is expected that many current structures and arrangements will also be modified. It is imperative for the Greek government to recognise that this transformation will *neither* automatically resolve the shortcomings of the national innovation system *nor* will be able to substitute the need for a national technology and national materials strategy. The Greek government should realise that one cannot expect distorted market forces to deliver the goods that even perfect markets cannot deliver.

CHAPTER 12: Recommendations on Private and National Materials Strategies

12.0: Introduction

The key aim of the present research was to develop and test the central and subsidiary hypothesis as discussed in chapters 1-11. Chapter 12 offers a set of private and national materials policy recommendations which follow directly from the insights, evidence and findings of the thesis for the case of Greece.

The following list of recommendations includes two distinct sets of recommendations. The first (section 12.1) is focused on private materials strategies and the second (section 12.2) is focused on national materials strategies and technology policy issues.

With respect to national materials strategies, given that a necessity for institutional changes has been identified, two sets of recommendations are put forward. The first is focused on suggestions for national materials directions (section 12.2.1) and the second (section 12.2.2) is focused on technology policy issues applied to or inspired by the materials case. The second set has wider implications for any other technological field.

12.1: Recommendations for private materials strategies

Given that each reviewed industrial sector operates under different conditions and given that the level of maturity and sophistication of the adopted materials strategies varies considerably among the reviewed companies/sectors, a uniform list of suggestions applying to all sectors would be inappropriate[1]. Therefore, the following recommendations reflect the findings of each separate sector and apply mainly to the case of companies operating under Greek ownership or companies retaining decision making autonomy.

[1] Contrast for example the case study of C2 and MU5, the two extremes with respect to materials strategies.

12.1.1: The cement and the consumer ceramics sector

The cement and the consumer and commodity ceramics sectors have developed the most sophisticated MSE strategies of all the reviewed sectors. Especially the MSE strategies of the cement industry and segments of the consumer ceramics industry are rivalling international examples. Hence it is recommended:

- To continue the efforts for the introduction of new materials in Greece.
- To further enhance R&D on incremental structural materials.
- To intensify materials-based diversification efforts (on the basis of new products based upon advanced materials) or to establish materials-based diversification efforts.
- To develop pre-competitive research activities as an "experimentation" strategy in order to identify potential opportunities for new markets and products. Functional materials should get priority.
- To balance the materials R&D portfolio with the introduction of new materials research.
- To develop stronger commercial and technological ties with construction companies (cement and consumer ceramics producers) or even acquire large construction companies and use them as a commercialisation channel of new products and new materials in order to enforce new commercial trends.
- Gradually enter new high temperature materials markets such as materials for energy production and high temperature chemical process (refractories).

12.1.2: The metals sector

The metals sector (especially ferrous metals) appears to be very conservative or even lagging behind international developments. Given that the ferrous metals sector is gradually coming under the control of the non-ferrous metals industries, the following recommendations apply to both cases.

- Enrichment and expansion of the current materials R&D activities, including the development of pre-competitive research capabilities which would target new structural materials or new metallic smart materials etc.

- Creation of a central materials R&D dedicated unit (for M5).
- Continuation and intensification of the efforts to introduce new products based on incremental or new materials able to be produced/manufactured with current S&P capabilities (SlimDek case as a model case for the ferrous industry).
- Focus on new aluminium based or advanced aluminium products for demanding applications (e.g. transport industry, demanding construction applications) with advanced performance created by mechanical processing carried out by existing S&P capabilities.
- Introduction of pre-competitive R&D activities targeting both structural (mainly) and functional materials (metals).
- Gradual diversification in advanced metals such as ferrous metals for electromagnetic applications and amorphous metals and advanced non-ferrous metals for electric and energy applications (e.g. wires and cables for electrical machinery and energy transfer/distribution).
- Formation of complementary alliances with foreign machinery companies for the development of new processing technologies (as the case of CON2, and M3).
- Development of stronger commercial and technological ties with construction companies or even acquisition of large construction companies which can act as a commercialisation channel of new metallic products and new materials in order to enforce new commercial trends.
- Development of links with universities and research institutions (the M5 case) for delivering pre-competitive materials research or for outsourcing non-crucial research activities.

12.1.3: The Defence industry

The defence industry suffers from perception problems rather than technological capabilities problems. As chapter 9 identified only MU1 and partially MU2 identify materials capabilities as crucial determinants for their operational competencies. All the other companies perceive materials technologies as crucial but purely supportive technologies and not as a basis for competitive advantage. Hence, given the present status and operational conditions of the sector, the development of multileveled and sophisticated MSE strategies has to meet the following preconditions:

- Identification of MSE competencies as a basic determinant for new products and services and as a fundamental core competency.
- The increase of R&D activities dedicating a considerable part to MSE technologies.
- Identification of specialisation areas (as in the case of M2).
- Increase of funding (state subsidies) exclusively for R&D purposes and underwriting of cash-flows for new product developments. Given that the sector is expected to remain under the jurisdiction of the Greek MOD, the current negative state intervention can be transformed into an advantage if specific budgets are allocated for exclusively R&D purposes over five to seven years horizons.
- Formation of closer ties with the Hellenic Standards Organisation and the GSRT.
- Formation of closer ties with the national research infrastructure (applies in the case of MU3, MU4 and MU5).
- Formation of complementary strategic alliances with Greek materials producers especially in the case of ferrous metals producers and *casting companies.*
- Formation of substantial complementary technological collaborations and alliances with both Greek and international materials producers.
- The provision of governmental support and international sponsoring of commercial networks - a measure also crucial for the internationalisation efforts of the construction sector.

With respect to the implementation of these recommendations the Greek defence sector can look upon the achievements of similar size defence sectors such as the Belgian defence industry and the notable Israeli defence industry which has managed to be not just an intelligent technology and materials user but an international military technology supplier. The technologies or military systems Israel exports are frequently supported by advanced materials and advanced materials technologies developed by the Israeli defence industry.

12.1.4: The Construction industry

As chapter 9 identified, only a handful of large construction companies (Ita-eighth class) and a handful of specialised construction companies have addressed the issue of management of technology. As such, the following recommendations apply to large and/or specialised construction corporations only.

- The development of durable corporate structures and the institutionalisation of internal mechanisms and technology-related activities based on tacit human knowledge.
- Identification, management and protection of technological core competencies.
- The development of technology policy divisions (with jurisdiction for outsourcing R&D activities) and the establishment (or enhancement) of R&D units.
- The creation of units exclusively dedicated to the study of materials technologies and their potential for construction applications (study and evaluation of *state of the art* materials and technologies).
- Application of simulation and modelling techniques in construction technologies and the in situ processing of materials.
- For the very large companies and/or the large specialised companies: establishment of materials dedicated R&D units with portfolios inspired by the three-stage Nissan-Ford R&D example illustrated on page... Both structural and functional materials can be included.
- Establishment of strong technological ties with large materials producers, and formation of long-term commercial and technological alliances with large materials producers[2] (such as the cement companies).
- Participation in the national R&D collaborative schemes.
- Contribution/support for efforts in the establishment of a construction technologies research centre.
- Apply pressure (through the Technical Chamber of Greece) for the development of efficient certification, quality control, monitoring and penalties enforcement mechanisms.
- Contribution/support of efforts for the establishment of schools for technicians and specialised workers.
- The establishment of links with venture capital companies in order to support expansions (establishment of new units) into emerging areas or for the transfer/development of new construction technologies.

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[2] Given that materials producers have considerable R&D experience, and given that construction companies can secure markets for new and advanced materials, the interaction can provide considerable benefits for the participants and especially for the Greek construction companies in both technological and organisational terms. The case study of CON2 and their relationships with their machinery suppliers proves that not only commercial but technology based alliances are possible in the Greek construction sector.

In addition, the sector needs urgent governmental support in the form of recognition as a special industrial sector, standards and quality certifications, the establishment of R&D supporting schemes tailored to the character and the needs of the Greek construction sector and the provision of specialised research infrastructure in the form of a research / technological institute dedicated to construction materials and technologies. From the author's perspective, CONEX3 must be institutionalised, and linked with ELOT (the national standards organisation) to create the nucleus of a national institute for construction technologies and materials.

It has to be underlined that for the construction industry many of these recommendations depend upon the constant flow of capital to large scale infrastructure projects and a better announcement planning of public works contracts. Nevertheless, the relevance of the preceding recommendations is demonstrated by the domination of the technology-intensive, large infrastructure projects by foreign companies which indicates that even Greek markets are no longer secure for Greek construction companies. Given that these trends are expected to spread from high technology to medium technology intensity projects and from large projects to medium size projects, and given the acceleration of the EU integration / unification, Greek construction companies face the challenge either to effectively respond or gradually be absorbed by international giants who wish to use them as their operators in the Balkans.

In a general frame, the above recommendations (all sectors) can be applied to most of the reviewed case studies. Their implementation however, would depend on individual cases, so that a detailed list of recommendations tailored to specific cases would be too long for the purposes of the present research.

12.2: Recommendations on National Materials Strategies

With respect to national materials strategies, the preceding chapters demonstrated that the implementation, and hence the efficiency, of the current national materials priorities is directly connected to the national innovation system's strengths and shortcomings. Given that a necessity for institutional changes has been identified, two sets of recommendations are put forward. The first is focused on suggestions for national materials directions and the second is focused on technology policy issues applied or inspired by the materials case. The second set has wider implications for any other technological field.

Several of the recommendations involve injections of public funds, either to subsidise existing, promising institutions or to crate new ones. Such funding is vital to stimulate national growth and competitiveness, and will be repaid many-fold within a decade. Besides the benefits of growth there will be efficiencies from the co-ordination of institutions and Ministries that must follow from a systemic overview of the national and international scene, the creation of a national "vision" and the development of plans to realise these vision.

12.2.1: Recommendations on national materials priorities

As identified in preceding chapters, Greece has the imperative need to maximise the technological and economic impact of the selected materials priorities in as many industrial and economic sectors as possible. In addition, it is imperative for the national materials priorities to sufficiently address important national needs. Energy production and utilisation[3] is the most outstanding but neglected example.

It is positive that many of the currently selected materials priorities (see section 8.2) target a wide spectrum of applications of complementary industrial clusters or sectors such as the structural metals and ceramics producers and utilises. It is recommended to widen and strengthen these directions.

Moreover, according to the presented evidence, Greece has the industrial and research capabilities for the development, efficient support and commercialisation of *incremental and advanced structural metals and ceramics for mainstream or "bulk" applications*. Specialised functional materials need markets which Greece either does not have or has not secured access to. In more detail, the following directions are recommended:

Metals

Ferrous metals: New, or improved through advanced mechanical processing ferrous metals (steels) for:

- Construction applications (e.g. the St4 case or the British Steel SlimDek can provide the necessary examples and references).
- Shipbuilding, off-shore and railway engineering.
- Energy applications (see below).

[3] As all parties underlined, energy intensive industries are at a disadvantage in Greece due to high energy cost. Greece obtains more than 87% (NPC 1991) of its annual energy needs from thermal sources such as the burning of fossil fuels such as lignite and oil- all of oil imported.

- Welding technologies (e.g. advanced welding materials, advanced welding techniques such as laser welding).
- Metal structures repair and maintenance technologies (such as corrosion control, damage detection and evaluation methods -including non-destructive tests-replacements etc.).

Casting technologies targeting both ferrous and non-ferrous metals for both high and medium technology intensity applications. The Greek government should also investigate the possibility of supporting the growth of a casting industry specialised in high-added value products.

Amorphous metals targeting electric and electronic applications.

Non-ferrous metals: The development of advanced or improved materials through advanced mechanical processing of aluminium and copper for:

- Construction applications, (e.g. panels, sandwich structures, light-weight decks and floors).
- Off-shore applications, transport equipment for railways and passenger ships.
- Lower electrical resistance materials (aluminium or copper based) for wires and cables.

Stainless-steel industry: Given the experience of the aluminium products industry which grew on M3's output, Greece should investigate the possibility to initiate and support the growth of a stainless steel industry based upon M2's Nickel output.

Ceramics

- Improved or advanced cements for niche or technologically demanding applications.
- New in-situ processing technologies based on materials systems or new materials for structural applications.
- Ceramic coatings and ceramic coating technologies of mainly metals or metallic components for energy, food production and chemical applications.
- Advanced light-weight structural ceramics with superior heat and noise insulation capabilities for building and other construction applications.
- Advanced porcelains or similar ceramics for chemical and medical applications.
- Support of diversification efforts into new materials with ceramic structure such as silicon fiber structures for heat insulation materials or ultra-strong open porous ceramics with ductile additions for commodity products.

Materials for Energy applications

Energy production: potential directions include both ceramic and metallic materials such as:

- Advanced refractors for thermal plants with potential spill-overs to metallurgical and all other high-temperature industries.
- Advanced ceramic coatings for metallic blades and other metallic parts operating under harsh conditions.
- High temperature corrosion resistance metals (a selection combined with coating technologies).
- Catalysis and catalytic filters for burning control and emission reductions.

Energy distribution: Metals with improved electrical conductivity (aluminium-copper alloys) for energy transfer/distribution wires and cables.

Energy Utilisation: advanced heat insulators for processing and structures insulation such as advanced bricks and tiles for buildings and other energy friendly structural elements.

Renewable energy sources: photovoltaic and other functional ceramics and materials for renewable energy sources.

With respect to *structural materials* Greece has the additional opportunity (and capability) to target advanced composites (PMC) for large scale applications such as construction and transport applications. The textile industry, the chemicals industry and the construction industry can be directly involved and benefit[4].

Functional Materials

The current national materials priorities include a limited number of directions targeting advanced functional materials (mainly of ceramic nature) such as optical fibers, materials for electronic and opto-electronic applications, materials for medical applications and a few other examples. The preceding analysis demonstrated that these directions are not sufficiently supported by domestic industries while their commercialisation in international markets is inhibited by established international players and their distribution networks. Thus, these materials primarily remain under the domain of research institutions and universities. Hence, it is recommended:

[4] Aslo see: Kaounides and Kottakis (1997). Advanced Composites: Entering the Commercial Era. Proceedings, (Vol.2) of The First Hellenic Conference on Advanced Composites, Xanthi, Greece, July 1997.

- Redirection of the aims of research from advanced functional materials for electronic / magnetic applications to research for electric and electric power applications.
- Functional materials for energy applications (e.g. photovoltaics, renewable energy applications).
- Strengthening of existing expertise under the scope of creating a strong exports industry specialising on high-quality, low-cost R&D services. The concept can also be applied in the case of advanced structural materials such as advanced composites or metals for aerospace applications (where universities have developed particular strengths).
- Functional/structural materials for medical applications: The ceramics industry (especially segments specialising on coating technologies and structural ceramics for aggressive environments) can gradually diversify into ceramic based or ceramic enhanced materials for medical applications. Moreover, given that large corporations avoid entering the area (due to high S&P costs[5]), high-technology specialised SMEs have the potential to cover the market gap.

Simulation and modelling

Greece has developed considerable strengths in software and modelling. Many of these strengths have already been employed by materials related industries and they have been identified as an important core competency. It is recommended to design national R&D programmes especially in support of these capabilities. The area can also support a strong export industry specialising on high-quality, low-cost software and simulation and modelling services designed to support not only materials and other industrial applications but also electronics, telecommunications and IT applications.

These recommendations are, in MSE terms, both technologically and commercially compatible (or even complementary) with the current industrial, research and technology infrastructure capabilities in Greece and with Greek and EU efforts to support SMEs. Especially priorities such as casting technologies, welding technologies, materials for medical applications and others are within the capabilities of an average Greek SME (100-200 workers).

[5] Each bio-medical implant must be tailored exactly to each individual patient (in terms of size and tolerances). That means that there can not be industrial production or massive S&P of the requested items. On the other hand huge capital investments for industrial production lines are not required. Thus the S&P of these "products" can be approached by SMEs.

12.2.2: Technology policy and infrastructure recommendations

General Technology policy recommendations

The materials case has uncovered considerable institutional weakness directly related either to national technology concepts or to their implementation. The following recommendations address both general technology policy concepts and implementation mechanisms of existing or recommended concepts. Even though these suggestions are tailored to materials paradigms and requirements, their concepts can be generalised and applied in many other fields.

A) Support of industrial sectors utilising materials classes identified as national materials priorities. The findings of chapters 8 and 9 revealed that many industrial sectors (e.g. construction industry, shipbuilding) are technologically unable to take on advanced materials technologies or R&D strategies as they have been excluded from participation in the national R&D collaborative schemes. It is imperative to support these sectors through a set of both specialised measures (e.g. dedicated R&D infrastructure-see below) and the introduction of new national R&D collaborative programmes with participation pre-conditions tailored to the special operational and technological characteristics of the targeted sectors.

B) Materials mission or application oriented R&D collaborative programmes.

Greece is the only EU country which has not yet developed national R&D activities bringing together all the achieved horizontal strengths in one specific technological field and goal. This absence is identified as a serious weakness of the Greek innovation system directly affecting not only materials but all technological fields. Henceforth, there is an imperative need for the government to introduce materials "mission and/or application oriented" R&D programmes with specific materials technological targets and specific applications[6].

C) Changes in the implementation of the existing national R&D programmes. That would include:

- Separation of budgets for new-comers and for re-applying successful participants. A pre-selected percentage, say 10-15% of the budget can be reserved exclusively

[6] The Japanese JISADAY programme, the mission-oriented R&D programmes in Germany and the American AMPP programme (summarised in chapter 5) can provide good examples of how vertical and horizontal actions can be successfully coupled, allocated and co-ordinated within mission or application-oriented R&D programmes.

for new-comers and the rest of the budget can be allocated to open competition as it is today. Thus, inexperienced new-comers will not directly compete with established "giants".

- Introduction of new programmes tailored to the needs of specific sectors. This will enable technology-weak sectors to correct for deficiencies.
- Design and introduction of "research contracts" tailored to specific scientific fields or technological applications.
- Introduction of R&D programmes clearly supporting pre-competitive but mission oriented research.

The last two measures would balance the established conflict of interests between universities, research institutions and companies for the same R&D resources and would re-introduce the necessary research division of labour among the involved parties.

D) Administration changes: Establishment of links and communication lines between the Ministry of Development, the Ministry of Education, the Ministry of Defence and the Ministry of Public Works[7]. The Japanese model of links between different agencies and organisations can provide valuable insights. These links should follow from a more systematic overview of new technologies and materials development at national level.

E) Introduction and enforcement of stronger and more effective **monitoring and supervision** mechanisms.

F) Utilisation of public procurements as long-term market securitisation and technology development instruments. Public orders and contracts for public works or other products and services can be consciously used as tools for the creation or accumulation of a critical mass of technological competencies and as supporters of high technology firms acting as nationals champions in various sectors[8] (e.g. the

[7] As Metcalf (1991) pointed out, it may be more important for the rate of progress in a technology not to spend more resources in R&D but instead to build communities of interaction between the different organisations articulating the technology in question. Who speaks to whom, with what frequency and to what purpose may be the crucial factor in determining the returns from an R&D programme (Metcalf 1991). In particular, materials technologies need this approach.

[8] The liberation of the system of governmental procurements within the EU does not seriously affect Greek suppliers and Greek industry for two reasons: the participation of international competitors is obligatory only if the value of the contract exceeds 138 million ECUs (only 20% of government procurements or contracts exceed this limit) and because 81.5 % of public sector procurements involve contracts with "public goods" companies (electricity production and distribution, transport, water and others) or other public sector services which have the legal means to by-pass EU regulation and directives (Kalogirou 1991, Politis 1992). As such, government contracts and procurements will continue to be a major opportunity and funding source of technological and industrial development.

telecommunications sector). Good implementation examples can be derived from Canada, Sweden, France, Israel and South Korea.

G) Introduction of technology fusion elements. The national technology policy priorities have not addressed the issue of technology *fusion*. Given that technology fusion (regarded by many as the next source of long-term competitive advantage) can take place by merging base technologies where Greece has strengths, it is questionable why efforts to this direction have been omitted by the Greek technology policy designers.

H) Creation and support of international networks. Any technology policy / national materials strategy in Greece is incomplete without international networking and products/services promotion mechanisms. The current policies have totally missed this point.

Research Infrastructure Recommendations

The materials case has uncovered a number of gaps in the national research infrastructure and certain endogenous weaknesses with respect to the support provided by the national innovation system. Given the shortcomings of the Greek innovation system, Greece needs a combination of research and technological institutions with the aim to:

- Be able to push forward the development and commercialisation of critical and emerging materials technologies in a way that many industrial sectors can take advantage (not just individual companies),
- Act as technology transfer and diffusion centres and provide high-technology services to industry in pre-selected technological areas of national interest, and,
- Act as a catalyst between public research and industrial needs.

Hence, it is recommended:

I) Support of the existing structural materials national R&D infrastructure with either the establishment of new research or technological organisations consistent with priority areas (e.g. Institute of Construction Materials and Technologies) or expansion and diversification of the established technological organisations.

II) Support and expansion of the role of the two technological institutions dedicated to metals and ceramics technologies (RI1 and RI2) including:

- The introduction of new departments and **separation** of certification / standardisation activities (which are practically simple services) from real R&D activities.

- Increase of public subsidisation for the R&D departments/activities and introduction of administrative changes enabling RI1 and RI2 to design and implement "research contracts" or large scale, application-oriented R&D programmes in metals and ceramics technologies.

Moreover, the established technological institutions can act as:

- Technological Intelligence gathering agencies in their fields.
- Incubators / sponsors of technologies and new high-technology companies.

To achieve these goals, they should be reorganised on the basis of paradigms of similar institutions in Japan, Germany and South Korea and the state should increase its subsidisation in order to provide the technological institutions the ability to develop their own R&D portfolios under the supervision of GSRT .

III) Establishment of two new research/technological institutions; one dedicated to construction technologies and construction materials and one dedicated to military applications including materials technologies.

IV) Support and expansion of the role of RI3: establishment of new divisions dedicated to materials technologies for energy applications (production, distribution, savings and utilisation).

V) Re-consideration of the R&D portfolio of the national research institutes on the basis of PS4's suggestion: "*... I wouldn't discriminate between basic and applied research; I would discriminate between useful and "blue-skies" research. Each R&D project, no matter if it is pre-competitive or not must be able to justify an ultimate tangible goal*[9]."

VI) Introduction of mechanisms promoting industrial networks and company-to-company links. For example, the Japanese Research Centre for Metals acting as a catalyst between industry, university and government has established a form of meetings called the *"salons"* which facilitate free ideas exchange between participating *metals producers and users* in order to integrate market ideas and users ideas in metallic materials R&D. RI1 and RI2 can play this role.

[9] For example, it is well documented that Greece has a serious energy production deficit and most of the energy is produced by conventional technologies (combustion of solid fuels and oil). In addition, Greece has climatological conditions very much in favour of the production of environmentally friendly energy. Functional materials such photovoltaics and insulation materials are within the capabilities of established research institutions and they have can be supported by huge industrial users such as the National Electricity Enterprise.

Education Policies

1) The introduction of mechanisms allocating scholarships for postgraduate degrees in fields tailored to the identified national materials priorities.

2) Reformation of PENED and SYN and introduction of thematic fields tailored to the national technology (and materials) strategy priorities. The postgraduate scholarship schemes of South Korea, Portugal and Taiwan can provide valuable paradigms in these directions.

3) Institutionalisation of continuous education schemes with focus on pacing and emerging technologies (in co-operation with professional associations such as the Technical Chamber of Greece and the Association of Greek Industrialists).

4) Re-introduction of professional education schemes such as technical apprenticeships for technicians and technologists.

5) Introduction of management courses (to supplement the existing production management courses) for scientists/engineers at graduate and postgraduate level covering Kaizen principles, systems engineering and management, interactive management, management of technology principles and project management.

6) Provision of Supplements to Higher Education Act, in order to institutionalise the allocation of researchers and the donation of private funds for the establishment of industry-related research centres or laboratories at universities.

7) Support and enhancement of the University Liaison offices: introduction of mechanisms able to promote or support commercial applications of academic R&D spin-offs.

8) Introduction of the concept of "company incubators" within universities and other research organisations.

Standards and Certifications

Given that Greece is a small country with limited industrial capabilities, the channelling of government funds to the support of standards development and support for technological advancement or for the harmonisation of the domestic industry to international technological developments would be regarded as a high level technology policy priority. Hence, it is recommended:

1) Immediate support of the Hellenic Standards Organisation with human resources and financial resources.

2) Introduction of modern inspection and quality control supervision mechanisms.

3) Introduction of units dedicated to construction and military technologies and/or advanced structural materials and their applications.

4) Adaptation of standardisation strategies for materials technologies as described in section 5.3.2. Given that for structural materials it is imperative to focus on *materials systems* rather than on individual materials and given that once an integrated system is certified by Greek standards it automatically gets EU certification (as happened in the case of photovoltaic boilers), the Greek standards organisation has the capability to support the materials directions suggested above.

12.2.3: Policy recommendations on international R&D collaboration

Given the findings and conclusions of chapter 10, it is recommended that the Greek government considers measures and mechanisms aiming to co-ordinate and support future participations in Brite/Euram programmes on the basis of the following recommendations. Given that:

- Many of the materials thematic fields where Greek industry increases its participation percentage in Brite/Euram programmes overlap with some of the basic national materials priorities (such as cements, commodity ceramics, construction technologies, simulation and modelling applications, construction materials, structural materials, incremental materials etc), and,
- Many of the regularly participating companies are involved with the production and use of the same materials groups,
- There are significant strengths in software, IT and simulation and modelling (which are primarily human resources based fields),

a national strategy should opt to further increase the percentage of Greek participation in these fields by exploiting the existing potential and experience and by providing support by lobbying for these areas in the EU Commissions. Insights on how Spain and Portugal have structured much of their national (and technology) policy priorities in alignment with the EU materials and technology policy priorities (De Andres 1993) can provide useful reference points.

In addition, the materials case and the high levels of Greek participation in the Brite/Euram programmes (such as research in advanced composites and advanced functional ceramics) demonstrate that Greece has the potential to develop a strong knowledge based industry exporting high-quality, low-price[10] R&D services in EU and elsewhere. Given that:

- There is a high concentration (surplus) of human scientific expertise in many emerging technologies within the research and technology institutions and the academia of the country but there is no adequate local industry to take advantage and support it (Vembos 1996),
- The labour cost of scientists and engineers (especially those with international postgraduate experience) is one of the lowest in Europe (Technical Chamber of Greece 1994) while it combines high quality, flexibility and skills due to high levels of exposure to international research,
- Greece has managed to established an excellent record of R&D services provision in the EU,
- The geographical and climatological advantages of Greece (and the considerable tourist industry);

Greece has the potential to develop a policy aiming at the development of a powerful **R&D services provision industry** which would function either as a major EU R&D projects contractor or would attract Direct Foreign Investment for the transfer of large scale R&D and design activities to Greece[11]. This "solution" can be of crucial importance for the survival of large segments of the Greek national innovation system, especially if the "high-technology" school of thought (see section 10.2.2) prevails in the design of future EU R&D programmes. Moreover, given that many large industrial units are under direct foreign control (see chapter 9), a sub-section of the same policy could target to provision of incentives in favour of the preservation and intensification of R&D activities in Greece. The high quality of human resources and the relatively cheaper salaries make Greece particularly attractive as a place for international R&D activities.

Moreover, given that many R&D activities in Greece are related to outsourcing of corporate R&D activities and given that many corporations committed to co-operative R&D or R&D outsourcing are operating as branches of multinationals with limited decision making autonomy (e.g. C4, M3, C2 etc), it is crucial for the Greek government to provide motives in favour of the preservation and intensification of

[10] While Greece has probably the highest concentration of human scientific expertise at both graduate and postgraduate level among EU countries, there is not adequate local industry to take advantage and support it (Vembos 1995). As such, the labour cost of scientists and engineers (especially those with international postgraduate experience) is one of the lowest and most flexible in EU (Technical Chamber of Greece 1992). Given the additional advantages of climate and life-style there is huge potential to be exploited.

[11] Singapore has managed to achieve something similar on a global basis.

R&D activities in Greece. Singapore has applied this policy without the low cost of living and human resources advantages of Greece. Switzerland has applied the concept in the field of theoretical physics. Greece has the potential to apply it in many emerging technologies such as materials, biotechnologies, computing and software, etc.

Finally, There is an emerging need for provision of information and administrative support for the participants in order to increase the level of awareness for EU R&D programmes within the limits and capabilities of the Greek industrial base (e.g. CRAFT and COST - see Annex 10.2). All interviewed experts observed that Greek industry can be activated successfully and *en-masse* in these programmes; however, administrative and information support is necessary in order to increase the level of awareness for these programmes.

Since 1985, the Ministry of Development and GSRT established a couple of specialised agencies aiming to promote the benefits of participation in EU collaborative R&D programmes and provide information for potential opportunities. But as the interviewed companies identified (and the governmental officials admitted) these agencies have just started to live up to their expectations. And again, there are no special arrangements reserved for the special needs of the MSE field or any other technological field. It is recommended that these agencies be strengthened and become field-specialised.

In conclusion, the directions and choices of a national materials strategy are defined by the national needs and characteristics but probably above all, by the **kind of vision** the policy makers have for the nation and national economic, technological and industrial development.

EPILOGUE

'It Is Not I Reiterating, It Is The Universe: All Is One And One Is All'.

(Heracleitos 650 BC)

The history of human knowledge has progressed during the last 300 years through extensive analysis of individual, and in many cases *artificially* separated, fields. The materials case however, demonstrates that synthesis of different principles is equally important (and challenging) for the promotion of human knowledge and the understanding of the cause of things.

I strongly believe that research must re-discover the virtues of the long-forgotten *Homo-Universalis* merits where the ability to creatively combine and synthesise knowledge (related to different fields) was equally praised and was equally beneficial with the ability to extensively analyse individual fields.

Probably the future ability of humans to understand and successfully manage for their benefit the ever rising complexity of knowledge critically depends on the ability to identify interactions and creatively synthesise principles and influences.

If... ,

'Happy Is He Who Has Been Able To Understand The Causes Of Things.'

(Virgil)

And Happiness Is...

'The Exercise Of Vital Powers, Along Lines Of Excellence,

In A Life Affording Them Scope.'

(Greek Definition Of Happiness)

Then I Have To Be A Happy Man....

Albeit,

"Ars Longa, Vita Brevis!"

How Tragic Humans Are...

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