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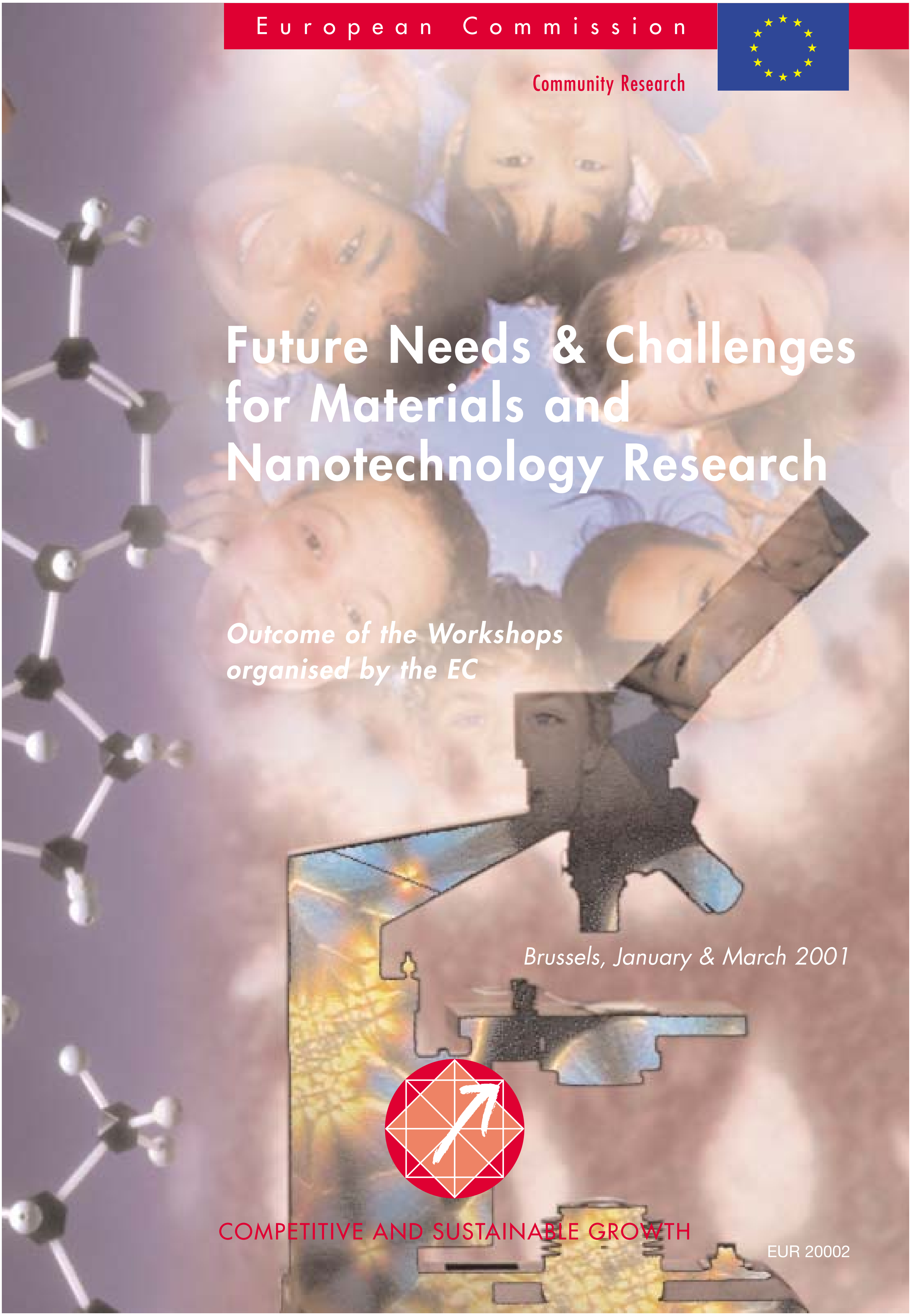

Future Needs & Challenges for Materials and Nanotechnology Research

Outcome of the Workshops organised by the EC

Brussels, January & March 2001

COMPETITIVE AND SUSTAINABLE GROWTH

EUR 20002

Future Needs and Challenges
for
Materials and Nanotechnology Research

Workshops held in Brussels
January and March 2001

Report prepared by

Materials Unit

European Commission
Research Directorate General
Directorate G / Unit 3

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I Foreword

In recent years we have witnessed unexpected technological advances thanks to the progress of new advanced materials. New ceramics, polymers, metal alloys, bio- and hybrid materials have substantially improved our quality of life through new and better products and services, generating wealth and employment. From medicine to the aeronautic and information sectors, these new materials have contributed to radically changing the European way of life. It is certainly true to say that materials are shaping our society.

Research on new materials will be more than ever a pre-condition to meet EU challenges. New materials will have the potential to assist us in attaining the goals set by the Lisbon Council. They will drive us towards a knowledge-based society and ensure a sustainable and competitive Europe.

But what are the strengths and weaknesses of the EU research in this field? What are the European needs and opportunities? What are the challenges that industry will have to face? Do we have the adequate resources? Is there a "material of the future"? What are the best mechanisms and issues to tackle? How can we guide curiosity to useful applications?

To reflect and debate these issues we organised two workshops. The outcome is summarised in this document. More than a strategic research paper, this document presents new concepts and ideas for future research and gives a new fresh image of the materials for the future.

Paradoxically, we were unable to identify "the material of the future". However we were able to define its wide characteristics and functions and the approach to be taken to ensure its sustainable production and life cycle.

Nanotechnologies were treated not as a stand alone topic, but as a promising and essential approach to develop new materials and exploit new properties. Their potential for characterizing and building up nanostructures will meet ambitious goals in all sectors. They will also have the merit of bringing together chemists, physicists, biologists, medical doctors, sociologists, etc.

It was also acknowledged that cutting edge technologies are no longer a domain only ruled by scientists. They have huge impact and affect us all. Society needs to participate in the debate on these technologies and, as both citizens and stakeholders, we need to take responsibility for how they are used.

This new way of carrying out research on materials and nanotechnologies implies addressing different issues, not only technological, but also socio-ecomonic, ethical and cultural requiring public acceptance and respect for human dignity.

Implementing the "**E**uropean **R**esearch **A**rea" can continually strengthen links between materials research, industry and society and make research more responsive and coherent than before. The new Framework Programme will bring us to a new era in materials research. Young scientists will have the opportunity to develop their knowledge, creativity and enthusiasm, but they will also have the challenge to combine research efforts in a new hybrid materials science, to increase impact across Europe, to ensure jobs and quality of life for all, to build and share a responsible way for a better society for tomorrow.

Luisa Prista
Head of Unit

II Acknowledgements

To individually thank the vast number of people who have given their time, effort and ideas to this brochure is a difficult task. I would like however to thank all the expert members of the panels, mentioned below, in addition to all those who have made written contributions. I would like to express my gratitude to my colleagues from the "Materials Unit" and from the "Policy Aspects Unit " who took this extra work on board and, by sharing ideas, made this constructive document possible. Finally I particularly would like to thank our Director, Mr. Ezio Andreta, who encouraged this brainstorming and who, by guiding our enthusiasm, will witness its implementation.

II List of Workshop Participants

Expert Panel

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Flemming Besenbacher, University of Aarhus, Institute of Physics and Astronomy, Denmark
Joao Bordado, Instituto Superior Tecnico, Portugal
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Petr Bour, Academy of Sciences of the Czech Republic, Czech Republic
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Wilhelm Engström, SW Univ. Agricultural Sciences – Pathology Dept, Sweden
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1. GENERAL CONTEXT

1.1 Introduction

At the beginning of this year, Unit G3 "Materials" of Directorate G "Industrial manufacturing research" from DG RTD organised two internal workshops involving 36 experts from different backgrounds and countries. Experts were invited to exchange their personal views in a brainstorming session on future needs and challenges for European Research on Materials and Nanotechnology.

The discussions led to the strategic conclusions and views presented in this paper. A synthesis of the technical outcome of discussions held in the workshops has already been distributed amongst the participants.

The aim of these workshops was to have a common understanding on major issues related to future materials and nanotechnology research activities in order to prepare the new Framework Programme (2002-2006).

1.2 Political background

Prior to the workshops, internal papers were distributed to launch the debate about the future fields of priority in materials and nanotechnology. In addition, the following documents constituted background information for the discussions.

- **The Treaty.** The European Union has always recognised the strategic role of research activities, being an integral part of the Treaty on European Union[1].

- **The Lisbon Council** of Research Ministers in March 2000 took an extremely important decision by setting the following new and more ambitious strategic goal for the next decade for the European Union: "*To become the most competitive and dynamic, knowledge-based economy in the world capable of sustainable economic growth with more and better jobs and greater social cohesion*." "Research" is now recognised as a future political priority, confirming that knowledge and technology are the driving forces behind economic growth and competitiveness.

- **The Communication of the Commission: "Towards a European Research Area" (ERA)[2],** represents a proactive response to safeguard our strengths and assets and to convert weaknesses into challenging opportunities.

[1] The Treaty on European Union (as amended by the Treaty of Amsterdam)
[2] COM(2000)6-18 January 2000

- A **"Proposal for a Multi-annual Research Framework Programme (2002-2006)"**[3], aiming at contributing towards the creation of the ERA, has been adopted by the Commission. "Nanotechnologies, intelligent materials and new production processes" has been identified as one of the eight priority areas.

1.3 Strategic items for discussion

The brainstorming focused on the following issues:

- **What are the challenges facing future EU industry (creation of wealth, preservation of resources, jobs)?**
  This issue requires clear international state-of-the-art, in addition to a view of the world-wide trends envisaged, and an identification of expected needs.

- **What are the technological priorities to tackle challenges (long-term, problem solving approach)?**
  This issue requires an in-depth knowledge of existing and emerging technologies, in addition to reflection on different approaches.

- **What RTD is to be funded at EU level?**
  This issue requires the respect of the main criteria of community added value, structuring effect and public benefit.

- **What are the mechanisms that might be used?**
  This issue needs to take into account the different types of needs, to identify relevant actions, funding sources and the means in which to implement them.

- **What complementarity and coordination with National Programmes can be foreseen?**
  This issue requires a mapping of the activities already carried out at national level.

[3] COM(2001)94 of 21.02.2001

2. SUMMARY CONCLUSIONS

2.1 European Reality: EU strengths and weaknesses

- **Knowledge, expertise and culture.** Europe has always demonstrated a solid knowledge base in materials science and nanotechnology. This can be continually enriched by supporting European research of excellence, which in turn will contribute towards developing and recruiting high-quality scientific personnel.

- **Safeguarding international leadership in strategic fields.** In many industrial sectors, such as chemicals, catalysis, polymers, superconductivity, nano-devices, ceramics and textiles, Europe's position at an international level is a leading one. In the field of nanotechnology, and also nanobiotechnology, Europe is rapidly positioning itself at both scientific and industrial level. Some new research intensive markets are emerging such as biomaterials and advanced materials; breakthrough technologies are contributing towards raising the competitiveness and the quality of jobs in some European sectors which are traditionally less knowledge intensive.

- **Low RTD financial resources.** Compared to its other major global competitors, Europe lags behind in terms of investment in research.

- **Shortage of infrastructures and common databases.** There is a clearly perceived lack of tools and techniques, infrastructures and data bases for materials in general, and more particularly for nano-science and nanotechnology.

- **Coordination and coherence.** It is acknowledged that Europe is suffering from lack of co-ordination of RTD activities at EU, national and regional levels. This is the case in the field of nanotechnologies for instance. Some areas such as superconductivity seem to be more co-ordinated at EU level.

- **Shortage of adequate human resources and of integration of skills.** The fields of nanotechnology and materials know no frontiers and the integration of disciplines, experiences and ways of co-operation within regions, nations and at an international level is crucial. Although Europe has been able to make significant progress in many scientific and technological areas, we are still suffering from a largely mono-disciplinary approach to problems that have global dimension. There is a shortage of careers with both multidisciplinary and interdisciplinary characteristics. There is a need to create a European culture in this field. Otherwise, Europe will soon face a shortage of researchers with the necessary profile.

- **Bridging the innovation gap.** Often, novel ideas do not reach industry and it has been noted that there are difficulties that hinder the bridging of industrial demand with the research world. As far as materials sciences are concerned, this can be seen in the challenge of converting results to commercial success. Some promising materials, in particular multi-materials and composites, are not on the market due to difficulties in the manufacturing process.

- **Encouraging integration of materials research into manufacturing.** The competitiveness of European industry will strongly rely on the exploitation of the performances of the new materials and on the ability of integrating material processing in the manufacturing cycle. Materials may be considered as the "frontier" for new manufacturing. To make the integration of the new materials development into the manufacturing cycle possible, will not only accelerate innovation, but will also contribute to the development of the new sustainable industries, products and services.

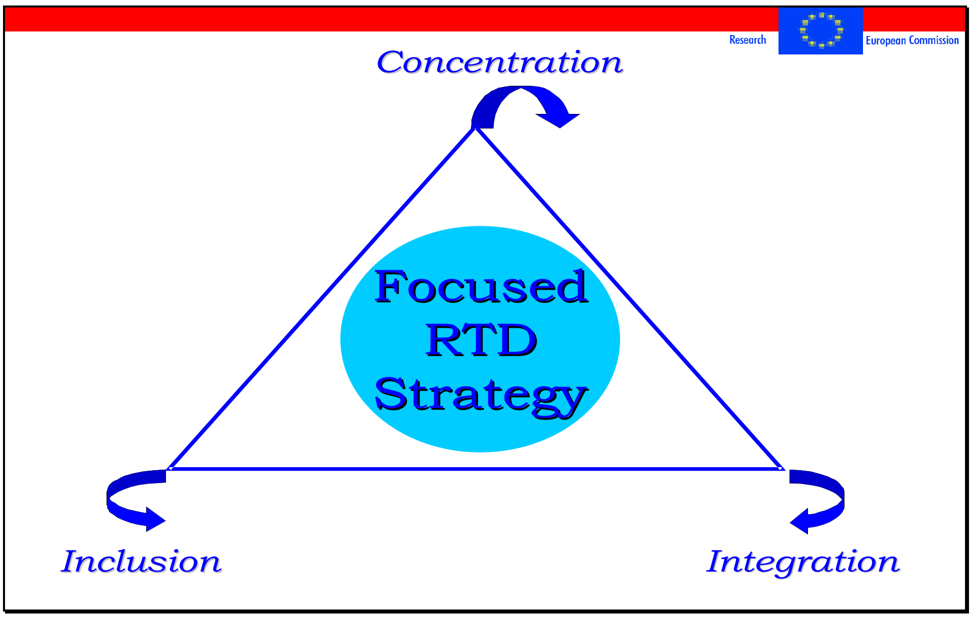
2.2 Pillars for an RTD strategy in the field of materials and nanotechnology

The strategy for materials and nanotechnology research relies on three main principles: concentration, integration and inclusion:

Concentration: means focusing on strategic priority RTD areas, covering the whole path from development of knowledge and ideas to their application in technologies and products.

Integration: refers to approaches, time and size scales, skills, subjects, disciplines, materials and technologies.

Inclusion: incorporates a strategy towards EU-wide cohesion.



2.3 EU RTD: Facing the Challenges

Future research in materials will lead us to the main industrial challenge of **sustainable competitiveness**.

”Sustainable competitiveness” appears to be a new wide concept of competitiveness embracing all goals set by the Lisbon Council. It is based on qualitative growth, bound to take into account concerns about environment, health, energy, employment, prosperity, public acceptance, culture and human dignity.

The way towards sustainable competitiveness requires a system approach and an overall integration of players, skills and activities, including research and innovative funding schemes.

- **Ensuring a better quality of life for everyone, now and for generations to come.** Technological advances on materials and related technologies have the potential to improve our quality of life by means of new and enhanced products and services, thus generating wealth and employment. Research activities can provide the economic growth and the consequent wealth level needed for social and environmental improvements at the basis of a sustainable development. This implies, in particular, the reorientation of means and models of production and consumption that are no longer compatible with the concept of sustainability. Future research will then not only provide innovative solutions to existing problems but will in particular offer new opportunities through the development of innovative materials with new functionalities and potentially improving the quality of life for everybody.

- **System approach and global quality.** New approaches and production paradigms are required to meet the challenge of "sustainable competitiveness". A shift from resource-based towards knowledge-based approaches; from quantity to quality; from mass-produced, single-use products to customer-tailored, multi-use products and product-services is needed. A qualitative growth can only be ensured by a global quality approach. These have to take into account all the steps involved in achieving the final product, the means and conditions under which it is produced, the environmental, social and human dignity considerations of the producers and the consumers.

- **Towards high-tech materials, products and services.** One of the means to maintain EU industries' competitiveness and jobs in the so-called "traditional sectors" is to accelerate the transition from traditional to high tech products and production. In this context, while research on the management of knowledge, personnel competence and skills becomes a key factor for competitiveness for all companies and organisations, research on new "knowledge based products and materials" offers opportunities not to be overlooked by these sectors. New added-value materials and products will create new markets, new knowledge-based jobs and will give a dynamic and innovative image of the EU manufacturing industry.

- **Promoting collaboration and networking.** RTD, as a part of the process towards sustainable competitiveness, should promote and strengthen collaboration and networking both across traditional and new scientific frontiers and among all research players, including industries, SMEs and spin-offs. A strategic RTD planning should therefore integrate all activities concerned: scientific effort, training schemes, socio-economic impact studies, public awareness and governance.

2.4 EU RTD: a new strategic approach

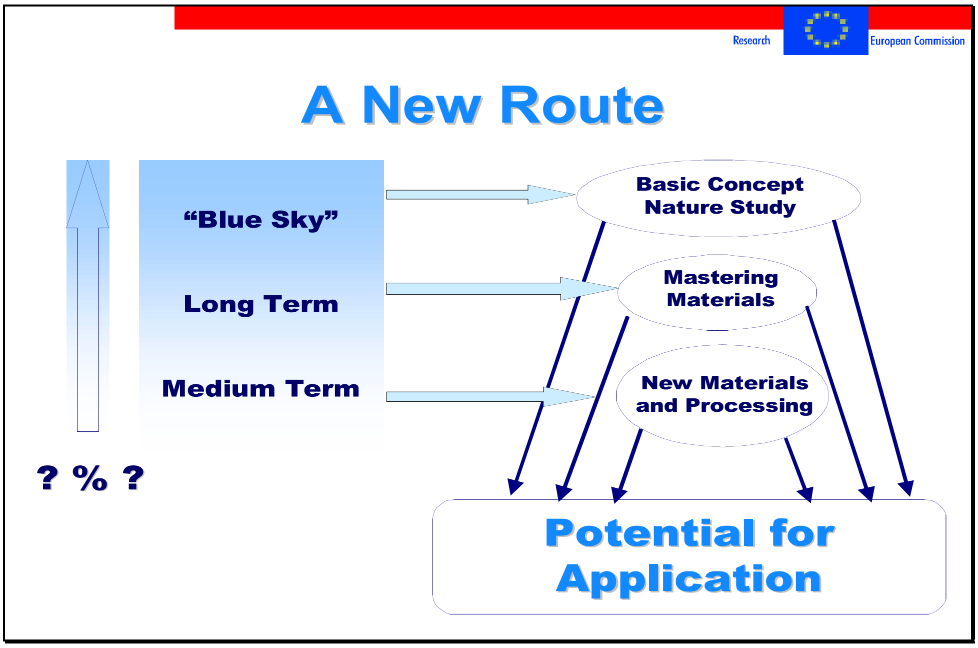
Future long-term RTD activities will require two distinct types of research:

- A new RTD approach based on openness and curiosity, leading to new frontiers of knowledge.

- A more problem-solving application driven approach.

In both cases, an open-ended targetted approach, as well as originality and excellence are key factors.

Both will contribute towards attaining Lisbon Council objectives by developing knowledge, improving competitiveness, sustainability, quality of life, and safety. Both will contribute by taking different routes to generate skills and employment.



- Only correct development**, excellence and mastering of knowledge** will lead to future sustainable applications. Industrial interest must be integrated. Long-term RTD will ensure future industrial applications

- **Opening to new interdisciplinary approaches** represents a new challenge for material scientists. This is particularly important in fields such as bioengineering and bioelectronics. Materials science, physics, biology, mechanics, surface chemistry, electronics etc are, for example, the disciplines concerned.

2.5 EU RTD: a Technological Approach

- **Towards smaller length scales.** It is recognised that there is a need for more emphasis on nanoscience and nanotechnology[4] but the need to address and integrate a bottom-up (creation of materials, control and manipulation at atomic level) and top-down approach (towards minaturization) has also been recognised.

- **Towards long time scales.** There is need for long term research, giving more space to creativity, originality and excellence allowing the so-called "blue-sky research" than in the past. This research will explore new and emerging scientific and technological problems and opportunities already anticipating future industrial applications.

- **Life cycle approach.** There is a need to consider all phases of the life of a material or product (recyclability, production, use and reuse of materials). This results in placing considerable emphasis on understanding phenomena, design and modelling tools (capabilities for modelling in the nano domain need to be expanded).

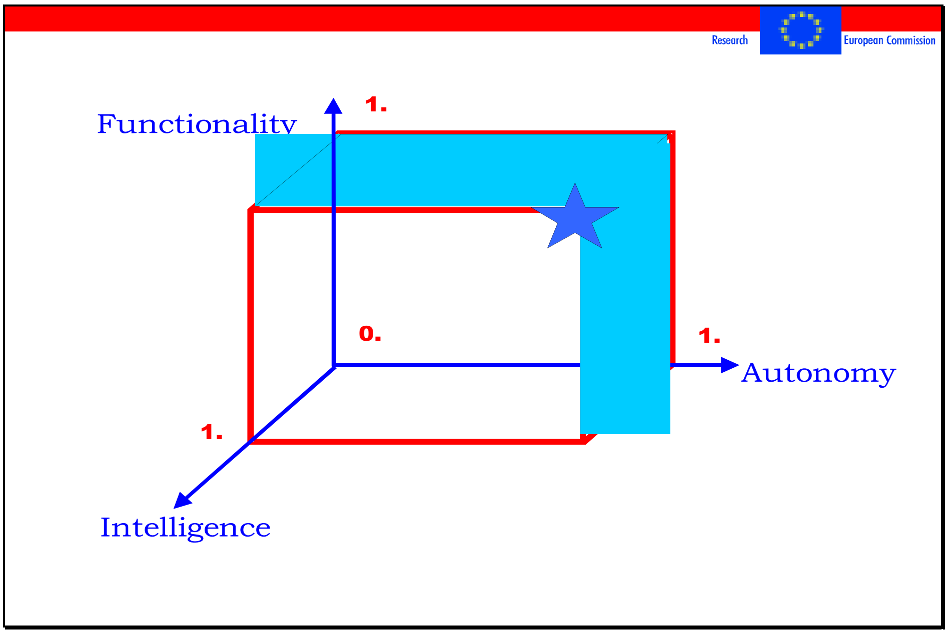
[4] Nanotechnology was considered in the broad sense as a new approach to RTD, and not only as a set of enabling technologies for creating and studying structures smaller than 0.1 µm down to atomic level. Nanoscience was not meant to be a science in its own right, but was also broadly defined as the use and further development of nanotechnology and microstructured materials in scientific research.

- **"Learn" from nature.** The objective is to consider the study of nature and learn from its vast paradigms, to increase the understanding in complex physi-chemical and biological phenomena relevant to mastering and processing novel materials. To learn from nature how to build up complex molecules from ubiquitous material resources (carbon dioxide, methane, water and hydrogen). A biomimetic approach might give rise to evolutionary materials and processes. Bio-inspired materials, biomimetic behaviour and relevant methodologies for developing multifunctional nanomaterials are key issues to be covered.

- **Hybrid technologies and materials.** Emphasis is given to multi-materials, composites and hybrid materials such as biomaterials and hybrid tissues. Interconnection of organic and inorganic-matter are key issues as well as the entire field of surface interactions and surface engineering. Nanotechnologies play a key role in this field.

- **Towards an Integrated Material.** Traditional science has already abandoned the distinction between functional and structural materials. For example, polymers have now expanded their function to include conducting electricity, emitting light or react and change form while stimulated. A wide range of actuators already exists in the market. These smart materials led us to sensors and to intelligent systems. The real challenge is to incorporate that intelligence into the material so that the intelligent "system" is no longer a system, but is embodied in the smallest part of the matter. New materials are also asked to perform different functions that should also be embodied in the same smallest parts of the matter. The final characteristic required is autonomy (auto-maintenance, self-repair, auto-diagnostics, auto-organisation, etc.).

  The materials of the future will be an integrated material where intelligence, multi-functionality and autonomy are designed at the smallest level.



2.6 EU RTD: needs and opportunities

- **Increasing and coordinating RTD in Europe**. The EU already holds a strong position in emerging markets and should capitalise and increase this through high quality research involving all players. Coherence and co-ordination is needed at all levels (regional, national and European).

- **New RTD culture.** Activities should also encourage curiosity and foster a new RTD & training culture within the EU, capable of innovation in new materials and able to enhance the integration between research on materials and industrial applications. There is a need to develop a "challenge-oriented interdisciplinarity".

- **New, appealing European careers** that cross traditional scientific frontiers are needed in order to ensure highly competitive and valuable human resources for the future. A dual aim exists: to attract young Europeans to invest in scientific and technical disciplines by providing them with a clear and confident vision for the future, and secondly to create in Europe the most valuable and highest level scientific amphitheatre that will attract and develop a world class brain bank.

- **Visionary research and the take-up of new ideas** are strongly dependent and have a considerable impact on high tech SMEs, including "start-ups". Links to technology opportunities and potential innovation initiatives with programmes at national and at European level, are essential to encourage and maintain Europe's natural dynamism in the area.

- **Keeping watch on the new frontiers of science-technology-society.** RTD activities in the field of materials and related technologies are gaining increasing strategic importance in shaping the future society. Visibility, public awareness and debate with the society are key issues for future research in materials and nanotechnologies. Actions to stimulate dialogue with the society and to give a fresh image of science and its potential impacts are needed.

- **Ethical considerations.** Cutting edges technologies are no longer a domain ruled by scientists. They affect all of us and we all need to step up and take responsibility for how they are used. Ethical considerations and reviews dealing with new materials, nanoscience and nanotechnologies will have to be established in order to allow "freedom of research in a responsible way" that is ensuring that all research developments are carried out in compliance with the fundamental ethical principles. Ethical considerations are particularly relevant in fields where the results are still unknown and where methods have a direct impact on human dignity, health, environment and animal welfare**.**

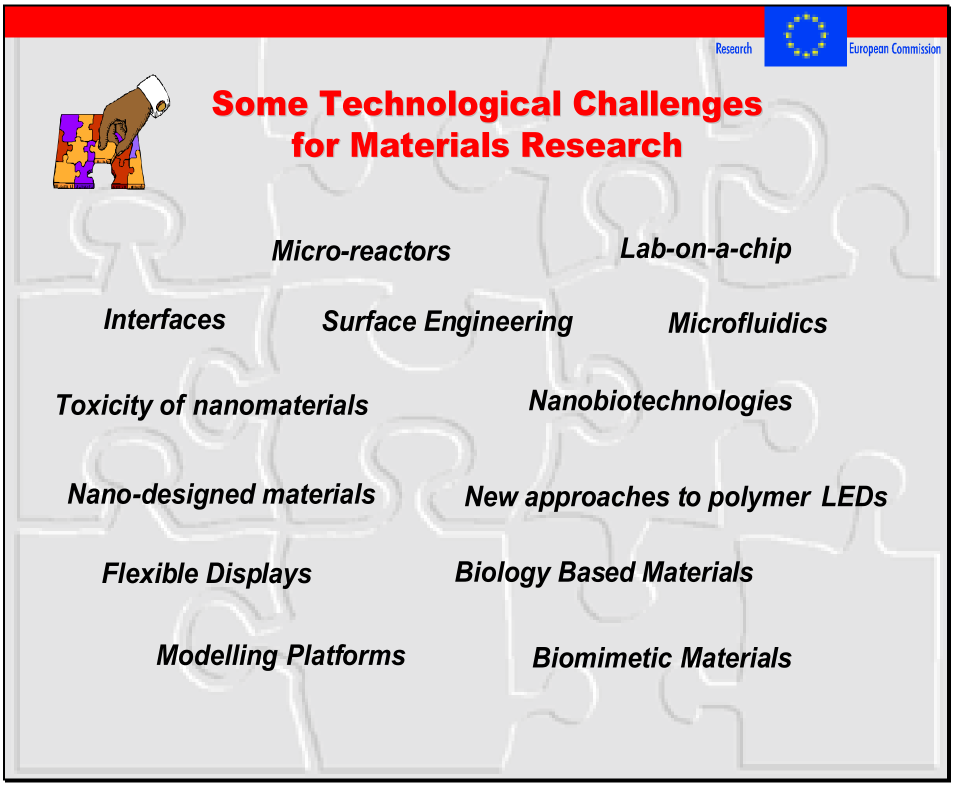
- **Cohesion.** Materials science and nanotechnology have huge potential for the future and will play an important role in shaping our future democratic society. Focused actions will have to be carried out in order to prepare the involvement of more countries and players, in particular in view of the imminent enlargement of the EU.

- **International cooperation.** Strategic research must take the importance of international relations into consideration. This is particularly crucial in the case of long-term integrated projects and for use of and access to large infrastructures. In the field of materials research, special attention should also be given to cooperation with emerging economies, whose scientific resources and human capital need to be emphasised and can be extremely beneficial for European RTD.

3. FACING NEW CHALLENGES

3.1 Some strategic RTD topics

The expert groups identified a wide range of topics with EU strategic importance, as well as emerging materials and technologies, requiring a considerable effort of integration of disciplines, skills, actors and activities.



3.2 Some specific RTD examples

Some specific contributions were put forward by industrial experts. These can be summarised as follows:

- **Catalysis materials.** Catalysts represent probably the most important materials produced today. Their economic impact is huge: as a market it represents a total of 10 bn _/year and more than 10% of our countries' GNP depends on catalysis. Products made by catalytic steps are estimated at 2000 bn_/year. In fact, catalysis plays an essential role in the production of chemicals, oil products, fertilisers, plastics, drugs and pharmaceutics. Catalysis has also a huge ecological impact: reductions in emissions from cars, power and chemical plants are also often performed by the introduction of catalysts.

  Very recently nature of the nanomaterials used as catalysts is started to be understood due to the introduction of new in-situ techniques and surface science tools such as the scanning tunnelling microscope, new theoretical methods and combinatorial approaches. This together with new procedures for producing nanosized materials open up for new design strategies for assembling the desired materials "atom-by-atom" an still holds an enormous potential for RTD. Equally promising is biomimetic catalysis, where the methods used by biological catalysts, enzymes, are used and transformed into inorganic analogues. Researchers at European university and industrial research laboratories have been in the forefront of many of these developments.

  In order to maintain world-leading position of EU catalysis research and to capitalize on the existing expertise, certain challenges need to be defeated: they encompass long term fundamental research on new catalysis, nano-catalysts and synthesis; development of novel tools; promote closer interaction between industry and academia; create new multidisciplinary scientists at EU scale capable of approaching catalysis in a fully integrated way.

- **Optical and Opto-electronic materials.** The new photonics materials are key progress enablers in a wide area of optical communication, data-storage and processing, as well as in sensing, display and lighting technologies. This is a very big and dynamic market, with end-uses in virtually every important industrial sector. As examples, several relevant challenges are outlined.

  The development of novel or improved electro-luminescent materials and devices, in essence light emitting diodes or lasers. These devices are used everywhere, in environmental sensing and display systems, in automotive dashboards and in optical communication systems. Key developments in this area relate to novel materials systems (for example Zinc Oxide), and to the ability to control materials on the nano-scale, leading to devices in which the light emission is related to the

3D nano-structure (for example quantum dot LEDs and lasers). In general, the light wavelength range (from infrared through visible to ultra-violet) is related to the materials system. A particular challenge is the development of highly efficient and large area white light emitters. These could replace the omnipresent light bulb, with potentially significant impacts on energy consumption.

In the longer term, the development of systems in which some or all of the data processing is implemented in optical devices – instead of in electronic devices. This would allow, for example, the concept of all-optical data communications networks, and would avoid the present system of "light to electronic" and "electronic to light" conversions. Novel non-linear optical materials are absolute requirements.

The development of more powerful optical data-storage technologies. One approach is to further increase storage capacity in 2 dimensional media, progressing on the well-known CD or DVD technologies. Novel approaches relate to 3 dimensional data storage, using interference phenomena and holographic techniques.

- **Organic electronics and organic opto-electronics.** There are many classes of organic materials that exhibit electrical and optical behaviour, electro-luminescence, conductivity and / or semi-conductivity. Such materials may be used to make organic opto-electronic devices, such as photovoltaic, light emitting (light emitting diode or laser) or data processors. The key target of organic (opto) electronics research is to develop a cheap, high volume alternative to mainstream (Silicon) based electronics technology, for applications where the performance requirements are modest.

  The organic devices will be relatively low performers when compared to their inorganic equivalents. However, the manufacturing technologies under investigation are relatively cheap – printing, nano-imprint, etc., and do not require the high levels of capital investment associated with inorganic electronics. Furthermore, technologies to produce the organics on large areas and on flexible substrates are under active development –allowing for example their integration on textiles.

  Early applications for organic devices are in items like displays, in smart cards, tagging devices, etc. On the longer time-scale, there is a wide spectrum of potential applications in many sectors, ranging from "smart and responsive textiles", and lab-on-chip or micro-reactors, to items like car dashboards or large data displays.

- **Magnetic materials.** The constant demands for higher information densities in magnetic data storage has stimulated the evolution from micro-scale to nano-scale. The discovery of giant magneto resistivity (GMR) about fifteen years ago has been the key enabling factor. GMR refers to a difference in the electrical conduction between different materials or within a material, depending on the relative electron spin. All magnetic disk read heads, and many magnetic sensors, are now based on GMR or related forms of magneto-resistance. In parallel, the magnetic material that makes up the actual disk is subject to continuing development, in which the ultimate goal is to have one magnetic nano-particle to represent one bit of information.

A second development in nano-magnetism is that of the "magnetic random access memory" (MRAM). MRAM relies on the electron spin dependence of the quantum mechanical tunnelling effect. MRAM is being developed as an alternative or a replacement of present-day CMOS based memory chips. The advantages of MRAM is that it is a non-volatile memory, and that it can in principle be miniaturised to well below 100nm per bit.

Other important developments in this area relate to the development of magnets and micro-magnetic systems with the capability to operate at higher temperatures, and to the development of cheap manufacturing technologies, such as printing and sintering, of magnetically active layers and devices.

Because magnetism is an extremely complex materials property, often requiring compounds of three, four or five materials to optimise required properties. It represent a great challenge for the material sciences.

- **Biomimetic materials for multisectorial applications**: The biomimetic approach to developing advanced materials is quickly gaining ground. Learning from nature and marrying Biology to Materials Science, this new field is generating fresh ideas and helping provide different solutions to existing challenges. In all living organisms nature produces a plethora of materials, architectures, systems and functions, which have been optimised during a long and tough evolution process. For example, some micro-organisms use a template mechanism to build protective silica shells: organic molecules are self assembled into larger-scale structures along the membrane of the cell, and these assemblies are subsequently used as structure directing agents for the synthesis of the amorphous SiO_2 shell. By simplifying the natural pathways using synthetic polymers, researchers are now able to develop similar biomimetic materials.

  An essential feature of these highly efficient biological materials is their structural organisation at many scales, as is the case for the ceramics and composites found in animal shells or in bone and dental tissues. The integration of these "intelligent" systems involves two important aspects: miniaturisation, to include many functions in a small volume, and hybridisation, to gain from associating mineral and organic components. From an industrial perspective, certain biomimetic materials inspired by specific performances are already produced nowadays, mainly for the transport, chemical and biomedical sectors. However, this field still holds an enormous exploitation potential. Long term research is needed, for example, in the areas of forming mechanisms, interfaces, hierarchically structured materials, natural polymers, biomaterials, gels, mesoscopic scale phenomena, robotics, etc. The domain of scientific and technological developments generated by this biomimetic approach is recognised as one of the most promising for the next decades.

- **Nanobiotechnology**. Nanobiotechnology is an emerging scientific and technological area, representing a multi-disciplinary branch of science. It addresses the interface between biology and materials sciences. Nanobiotechnolgy is based on the idea that the ability to design synthetic materials on a nanoscale towards molecular architecture of biologically relevant molecules will ultimately lead to the integration of artificial and biological matter. This concept has enormous technological potential with possible applications in such areas as environment, biomedical sensors and artificial tissues. The following technological RTD mainstream activities can be distinguished :

  – The application of solid-state nano-technologies to biological entities, relevant for 'Lab-on-a-chip' for medical and environmental applications.

  – The combination of bio-molecule functionality with inorganic or organic materials, needed for instance in targeted drug delivery and leading to a huge improvement in quality of life and reduction in health care costs.

  – The surface structuring of materials at nano-scale for enhanced biological compatibility essential for implants

  – Techniques for the study of biology at nano-scale and molecular level which are crucial for the development of the entire field of nanobiotechnology.

  Activities will cover a wide spectrum of development time-scales. For elements like transplants, a big market already exists. For 'Lab-on-Chip' devices, the present market is small, but a strong growth is predicted within the next few years. Novel targeted drug delivery systems are at an active research stage, but may take significant time to reach markets, if only due to regulatory procedures. Techniques related to single molecule manipulation and detection, to molecular self-assembly are at an early stage of research.

- **Superconductivity.** Breakthroughs in the field of superconductivity are intimately related to progress in materials research. The technical performance of HTS superconductors is often superior but production and material costs are still too high. There is strong competition between the EU, USA and Japan, each region having different centers of gravity. For instance new research efforts have started in EU, and Japan regarding the improvement of BISCO tapes, while for the YBCO ones, Europe has developed a strong activity, at least equivalent to that in USA and in Japan.

  Concerning HTS electronics the industrial engagement is much higher in USA and Japan; in contrast, for power applications, Europe has a very strong position. In order to maintain leading positions and become competitive in others, coordinated research efforts need to be undertaken since a great variety of material aspects are involved, stretching from the study of bulk materials, to the development of long conductors with filaments (or coatings) of sizes down to ≤1 μm. The fabrication of HTS devices requires the technology for local material control at a scale of a few nm. Both grain boundaries and flux line dynamics are two important limiting factors that need to be tackled on a nanometric scale. The application field of superconductivity is quite extensive involving large-scale energy related applications, (transformers, power cables, current limiters, magnets) and small scale electronics related applications (passive/active signal processing, current leads for low temperature systems, etc). HTS magnets can be used in various domains, like medical (MRIs, SQUIDs), high energy physics (particle detection), NMR spectroscopy, etc. while filters for mobile phone base stations have already made it to the market.

- **Composites and "multimaterials**". These refer to an assembly of different materials providing more advanced properties that those of each of the constituents. The European composites industry has grown very fast, with just very few companies in the 1950's to about 15,000 today, most of which SMEs. A major development and implementation of new lightweight composite structures can be found today in diverse sectors (construction/civil engineering, road, air water and rail transport) with the most high-end applications found in aeronautics. Europe demonstrates a leading role in chemistry and composites with a very strong know-how. This is an area where the high quality R&D findings should pervade the European industrial activity more easily, as they appear to do in other competitive economies.

  There is an unprecedented potential in the sector for an accelerated growth in both existing and new materials. New matrices and new fibres (including natural ones) and compounds need to be explored to attain materials with novel functions, (eg polymeric composites that can conduct electricity), or to enable upgrading residual materials. Bio-composites, molecular electronics, biomimetic materials, nano-phasic composites, ceramic or reinforced metal matrix composites (eg Al, Mg, Rare Earth, carbon fibre Cu), etc. are attracting the attention of several research groups worldwide. The implementation of most of the new ideas seems to require a multi-disciplinary coercion that encompasses design, synthesis/processing, fabrication and production aspects.

- **Materials for medical applications.** Biomaterials and medical devices represent a fast emerging market that is estimated at about 260 billion _ world-wide for the year 2000 alone, with Europe's share being about 30 %. Biomaterials research in Europe is of very high quality and in strong competition with the USA who are still the world leader. On the other hand, Europe holds its position of excellence in specific areas like tissue engineering.

  The new and active life-style of citizens and the ageing European population need multidisciplinary materials research which are strongly oriented towards promising developments. An examples is hybrid tissue engineering, that can satisfy the ever growing demand of tissue and organ replacements or repair avoiding dependance on human donors or xenotransplantation, and all related risks of rejection, infection or transmission of diseases.

In addition, technologies aiming at the improvement of the bio-compatibility of all types of implants through, for example, bio-active coatings and nano-structures or newly designed or bio-mimicking materials should be strengthened. Nano-biotechnological approaches are also required within the development of materials for new targeted drug delivery systems to fight against diseases that have been so far incurables. Related technologies like minimally invasive surgery, non–invasive diagnostic systems, including reliable biosensors, also need further continuing support.

- **Intelligent textiles.** The textile and clothing sector is an important part of the European manufacturing industry, giving employment to more than 2 million people. Its importance for social and economic cohesion is increased by the fact that it is dominated by a large number of small and medium-sized enterprises, which are often concentrated in particular regions, thus contributing greatly to their wealth and cultural heritage.

  Being one of the oldest sectors in the history of industrial development, the textile and clothing industry was often referred to as a “traditional industry”, as a sector belonging to the so-called “old economy”. During last decade, EU industries in this sector have undergone significant restructuring and modernisation efforts, making redundant about one third of the total work force, increasing productivity throughout the production chain, and reorienting production towards innovative, high-quality products. The main key for competitiveness is recognised as being the shift of this sector to an high tech sector by the introduction of emerging technologies (such as plasma technology, IT, biotechnology and nanotechnology) and especially by the development of new knowledge-based materials and products.

  Technical textiles already represent a growing market for transportation, healthcare and high-tech clothing. New cross-fields of research (materials science, medicine, chemistry and electronic) are emerging and demonstrating that research at materials level is fundamental to raise EU competitiveness in the sector. A wide range of innovation is to be expected. Examples are the development of multi-functional textiles by fibres surface functionalisation (such as anti-bacteria, anti-mite, release of drugs via textile interface with the skin) the development intelligent textiles (for working protection, for blood pressure control, for comfort) the generation of new non-wovens for structural applications (railways, aeronautics, construction etc).

For further information relating to the Workshop on Materials and Nanotechnology Research, or the Competitive and Sustainable Growth programme in general:

Http://cordis.lu/nanotechnology/

Http://europa.eu.int/comm/research/growth

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