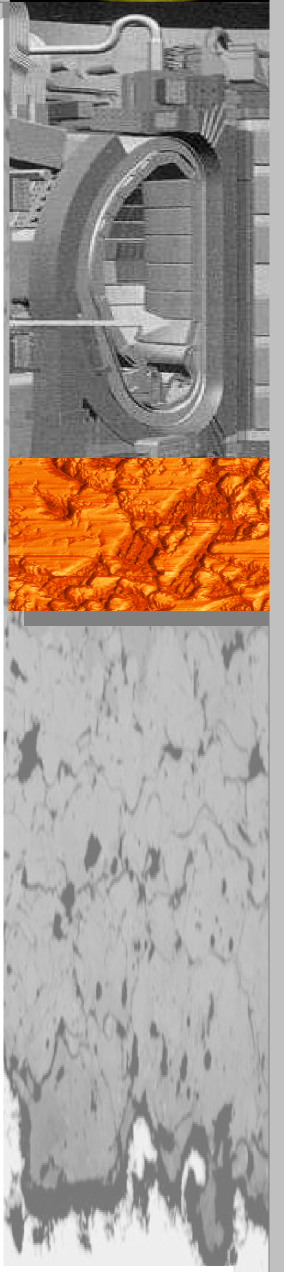
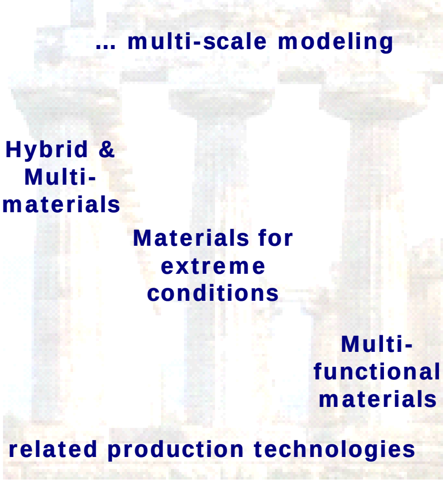


EuMaT

Materials for Life Cycle



... multi-scale modeling

Hybrid &
Multi-
materials

Materials for
extreme
conditions

Multi-
functional
materials

... related production technologies

Priorities for the forthcoming calls

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Technical Foresight and Resources needed for the realization of the EuMaT Roadmap activities ("Implementation Agenda")

For the forthcoming FP7 call(s) the Focus Groups have formulated 5 priority topics combining the following aspects:

a. EuMaT Focus Group priority topics, namely:

FG I	Management and Coordination
FG II	Materials
FG III	Materials Production Technologies, Testing & Characterization
FG IV	Materials modeling
FG V	Horizontal issues – coordination groups

b. FP7 priorities, namely:

1. Health
2. Food, Agriculture and Biotechnology
3. Information and Communication Technologies
4. Nanosciences/ technologies, Materials and New Production
5. Energy
6. Environment and Climate Change
7. Transport
8. Socio-economic Sciences and the Humanities
9. Space and Security Technologies, and

c. EuMaT 5 priorities, namely:

1. multi-functional engineering materials with gradient properties
2. engineering materials for challenging application conditions, including high-temperature and light-weight
3. multi-material (hybrid) systems where advanced materials are combined with more conventional / structural materials
4. relevant materials technologies and
5. multi-scale modeling

The priorities for the forthcoming call(s) are then defined as a combination of the most relevant of the above items.

The format for each proposed topic (not project!) is given below and should be the basis for the definition of the "bullet points" in the calls:

<table>
<tr><td colspan="4">RTD TOPIC:
...</td></tr>
<tr><td colspan="4"><i>Brief description of the topic and rationale at a level which you would find in a work program</i></td></tr>
<tr><td colspan="4"><i>Main development issues and targets at a level which you would find in a work program</i></td></tr>
<tr><td colspan="4"><i>Expected impact in quantifiable terms at a level which you would find in a work program (please try to avoid quantifications like "improvement of machining speed by 20%", which as such do not give much useful information without additional data about the specific application, size of the market etc...)</i></td></tr>
<tr><td colspan="4"><i>Sectors addressed:</i></td></tr>
<tr><td colspan="4"><i>Required RTD investment:</i> xxxx €</td></tr>
<tr><td colspan="4"><i>Implementation priority/justification: Prioritisation within the topics put forward in the SRA of the ETP, taking into account critical dependencies etc.: "1st priority because…. (largest return on RTD investment/prerequisite for further research/etc.)"</i></td></tr>
<tr><td colspan="4">Notes/comments: <i>e.g. possible coordination needs with other thematic programs</i></td></tr>
<tr><td>Elements to be included in the call</td><td>State of the Art</td><td>Vision/targets</td><td>Forecast materialization</td></tr>
<tr><td><i>Description of the elements to be included in the call (For example, a RTD topic "Flexible assembly systems could include the following elements: integration of automated and manual working places; development plug & produce function elements; development in-line control for assembly systems; simplified user-interfaces & programming tools.)</i></td><td><i>In terms of process/technology, organization (if applicable), tools (if applicable)</i></td><td><i>In terms of process/technology, organization (if applicable), tools (if applicable)</i></td><td></td></tr>
</table>

EuMaT TOPIC:

1. Materials for Energy Supply and Environmental Protection

Brief description of the topic and rationale at a level which you would find in a work program

Across Europe and the rest of the world, there is a need to establish a sustainable approach to energy, in terms of its production, use, conservation and management whilst at the same time meeting strict economic and environmental targets.
The global focus on Energy & the Environment should be used as a driver to further develop world-class knowledge and capability in Europe in the field of materials for energy generation, transmission, storage, and conservation. The opportunities for, and contribution materials can make to, reliable and sustainable forms of energy generation (e.g. fossil & renewables), and conservation (e.g. construction, manufacturing, transport) are enormous and the EU, with its acknowledged expertise in Materials Science, must take these opportunities to further develop its world class expertise which must be retained within the EU materials community. The technologies must then be implemented to secure jobs in areas such as materials production, processing & manufacturing, particularly in the high added value technologies associated with these industries, for which Europe is renowned.

By necessity, this programme will be a multi-sectoral, cross-cutting activity involving amongst others; Energy, Construction, Transport & Manufacturing industries. In particular, transferable material solutions from other sectors and across the entire Energy portfolio should be examined to achieve maximum competitive advantage for the EU. Whilst the need for developments in materials for clean energy generation may be obvious, developments to underpin energy conservation and storage, as part of a balanced future Energy strategy, must also be put in place. The programme will also, by necessity, need to cover the whole spectrum of material classes from metals, composites, carbons, ceramics, to nano-, functional and multi-functional materials, as well as novel methods for on-line and off-line condition monitoring.

Main development issues and targets at a level which you would find in a work program

1. Materials for the generation of electricity, heat and clean fuels (e.g. hydrogen, bio-fuels, etc.). These will include high temperature materials, coatings and functional materials for zero-emission fossil fuel, nuclear, biomass and waste-fired power plant, including fuel cells, as well as materials for other renewable energy technologies including solar (PV & thermal), wave/tidal and wind.
2. Materials for energy transmission and storage. This should include materials for electricity, gas and hydrogen distribution, pipelines for captured $CO_{2,}$ as well as H_2 storage, advanced battery technologies and other methods for energy storage.
3. Materials design and selection for rejuvenation and recyclability, thus maximizing sustainability and providing new approaches to design of engineering systems and ‘eco’ buildings.
4. Materials for energy conservation and efficiency in use. This will include materials for construction e.g. glass, insulating materials, ceramics, coatings, etc. It will also include development of lightweight materials for automotive and aerospace sectors in order to reduce fuel consumption and emissions.

Expected impact in quantifiable terms at a level which you would find in a work program

To stay below the proposed 2^0C temperature rise target, greenhouse gas emissions need to be reduced by at least 50% compared to 1990 levels by the mid-21st century; this requires the deployment of zero-emission technologies to start in the very near future. This target will only be achieved using all available approaches to reduce emissions in generation and reduce demand/optimize use by the consumer. This requires cross-sectoral materials development for clean energy generation (fossil & renewables) using CO_2 neutral energy sources/fuels or carbon capture and storage, energy storage (e.g. H_2), transmission, & conservation (in buildings, manufacturing and transport).

For example, by 2020 it is our objective to develop materials for use in clean fossil fuel power plants with multi-pollutant control which will deliver, in an economically viable manner, near zero emissions of CO_2, or be in a position to include CO_2 capture systems (i.e. capture-ready). With full deployment of these technologies worldwide, CO_2 emissions could potentially be reduced by ~100GtCO_2 over a 50 year period, thus firmly establishing zero emission fossil fuel as a major component in the portfolio of energy systems offering low CO_2 emissions around the world. Given that historically EU industry has supplied close to 50% of the global fossil fuel power plant market and has an excellent reputation for innovation in the development of advanced systems and components, this vision will place Europe at the forefront of industrial/economic competitiveness.

If we take into consideration the role materials can also play in other areas of energy generation and conservation, their potential impact on CO_2 emissions is enormous.

Further examples include:-

- new materials for more efficient renewable energy generation (e.g.. photovoltaics, fuel cells)
- energy conservation through materials development for the building/construction sector.
- lighter weight materials for the transport sector to improve their efficiency and reduce emissions

Sectors addressed:

These include:- Energy, Materials, Manufacturing, Transport, Aerospace, Construction

***Required RTD investment:* 500M€**

Implementation priority/justification: Prioritisation within the topics put forward in the SRA of the ETP, taking into account critical dependencies etc.: "1st priority because…. (largest return on RTD investment/prerequisite for further research/etc.)"

Protection of the environment & minimizing the impact of climate change are the most serious challenges faced by humankind today and must be the number one priority. Probably the greatest impact in alleviating the problem will be made by reducing CO_2 emissions. The global focus on Energy & Environment should be used as a driver to further develop world class knowledge and capability in Europe in the field of materials for energy generation, transmission, storage, and low energy processing and energy conservation. This in turn will re-vitalize many industrial sectors within Europe, increasing employment and wealth creation.

Notes/comments: e.g. possible coordination needs with other thematic programs

Coordination with other ETP' e.g. ZEFFPP, ESTEP, ACARE, MANUFUTURE, SUSCHEM, ERTRAC, will be paramount. Also collaboration with networks such as KMM and Extremat will be needed

Elements to be included in the call	**State of the Art**	**Vision/targets**	**Forecast materialization**
Key action 1: Materials for power and heat generation (e.g. fossil fired power plant, renewables), heat recovery (e.g. in chemical plants) and low CO_2 fuels (e.g. H_2, biofuels,). These will include high temperature materials (metals, refractories & composites), coatings and functional materials for fossil-fired power plant (including fuel cells and /or CO_2 capture & storage) as well as biomass & waste fired plant. Also, materials for other renewable energy approaches including solar (thermal & photovoltaic), tidal/wave and onshore/offshore wind. Key action 2: Materials for energy transmission/ storage and the transport of CO_2 and H_2. This should include materials for H_2 storage, CO_2 pipelines, advanced battery technologies and other methods of energy storage. Key action 3: Materials for recyclability and sustainability. This will look at the sustainability issue to develop new materials and methods of recycling and re-use of existing materials in new high technology systems, with a systematic approach to environmental considerations into product and process design and manufacturing- 'Design for Environment'/'Design for manufacturing' DfE/DfM. Key action 4: Materials for energy conservation, This will include materials for green buildings and construction with low environmental impact, e.g. glass, insulating materials, ceramics, smart materials, etc. Key action 5: Materials for lightweighting. This will be of particular relevance to the automotive and aerospace sectors. Key action 6: Materials selection and modeling. This will include improved materials databases, property assessment methods and through life cycle modeling from alloy development, process and production modeling to the modeling of performance in service.	For all of the key actions the current state of Materials Development of a broad range of materials has to be enhanced to improve their resistance to more arduous operating conditions and monitor their performance in service (on-line and off-line) and increase service lives. This includes high temperature materials, corrosion resistant materials, smart materials and coatings for corrosion, oxidation, wear/erosion & thermal protection as well as membranes and other functional materials (e.g. for H_2, O_2 or CO_2 separation). For transport and 'lightweighting' the development of Composites and aluminium, magnesium, titanium alloys will be necessary. Generic areas such as Materials Modeling (including through life cycle) will have to be further enhanced along with lifetime prediction, testing & characterization methods.	'Development of the EU as the world's centre of excellence in Materials Engineering for 'Energy Materials.' This will provide multi-sectoral support across Europe (in particular the manufacturing sector, automotive, aerospace and energy), enhance the competitiveness of these sectors, increase their contributions to GDP and increase/maintain employment in Europe in specialist materials technologies.	2010-15

EuMaT TOPIC:

2. Development of new materials tailored to next generation transportation.

Brief description of the topic and rationale at a level which you would find in a work program

Materials will evolve in the next ten years in order to follow step-by-step the strict emission reduction requirement and the increasing demand for structural performance and multifunctionality. Lightweight overall requirements will be an important issue that could be achieved through focused material development and more efficient and rationalized deployment, with innovative design solutions which enable their full potential to be achieved. Moreover, the emerging needs due to the industrialization of new countries will modify the present availability of materials around the world. The drivers for the evolution of automotive materials application can be identified as: i) emerging strict requirement in terms of reduced weight and improved structural safety; ii) innovative and personalized product; iii) environmental and sustainability issues; iv) socio-economic environment; v) regulatory climate; vi) new map of end user.

New materials need adequate manufacturing system including new forming, joining, assembly, surface protecting and painting processes. A pre-competitive effort is needed to upscale the artificial materials fabricated in the laboratories to the industrial plants (emphasis should be placed on the integration of new materials into macro-scale assembly lines) and to set-up automotive manufacturing processes from the base material to recycle-reuse, mainly in term of cost, investments, environment. Furthermore, the advent of nanotechnologies offer today a unique opportunity to design artificial materials whose properties can be tailored to the next generation vehicles requirements. Thanks to the nanotechnologies advances, artificial Nano-Assembled Materials (NAMs) can be designed and fabricated to fit specific application requirements. Different nanosized materials can be properly assembled at the nanoscale to make up a new hand-made raw material whose properties are the result of its nano-components and their spatial distribution. The interest in these materials has been stimulated by the fact that, owing to the small size of the building blocks (particles, grain, or phase) and the high surface-to-volume ratio, these materials are expected to exhibits unique, mechanical, optical, electronic and magnetic properties. The properties of NAMs depend on the following four common structural features: (1) the fine grain size distribution (<100 nm); (2) the chemical composition of the constituent phases; (3) the presence of interfaces, more specifically, grain boundaries, heterophases interfaces, or the free surface, and (4) interactions between the constituents' domains. The presence and interplay of these four features largely determine the unique properties of NAMs.

Main development issues and targets at a level which you would find in a work program

In the car industry, main general research issues have been identified according to the vehicle foreseen future advances:

- Development of new light materials for vehicle structures (car-body & chassis)
- Development of new materials for interiors
- Development of new materials for light-weight wiring
- Development of new materials for power train
- Energy efficient manufacturing processes for efficient fuel vehicles
- New joining techniques and advanced assembling/dismantling processes
- New nanostructured materials for automotive sensing technologies
- New nano-assembled materials with integrated sensing and actuating capabilities
- New composites with enhanced damping properties and superior damage tolerance

Expected impact in quantifiable terms at a level which you would find in a work program

Artificial materials development/improvement to enable:

- the automotive industry to improve efficiency (reduced fuel consumption, pollution and costs) and safety;
- the use of innovative and effective integration of emerging and developed mixed material integration technologies;
- penetration of mixed material structure concepts;
- New manufacturing processes for automotive industry (OEM + tier1 + suppliers + SMEs)

Sectors addressed:

Automotive sector, aerospace and telecom, railway, ship building, domestic appliances.

***Required RTD investment:* 150 M€ (funding) Integrated project, NOE, Streps**

Implementation priority/justification: Prioritisation within the topics put forward in the SRA of the ETP, taking into account critical dependencies etc.: "1st priority because…. (largest return on RTD investment/prerequisite for further research/etc.)"

1st priority: development of new materials for car-body, chassis and wiring to improve efficiency, in particular through weight reduction;
2nd priority: development of artificial materials of new physical properties for new functions
3rd priority: take up of the artificial materials fabrication processes – from laboratory to plant.

Notes/comments: e.g. possible coordination needs with other thematic programs

This research need is integrated to the Design and Production research strategy described in ERTRAC and Technology Platform, particularly with "Vertical Activities" related to Materials and Production and Global Competitiveness and with "Horizontal Activities" on Standards and Design Data and Logistics. Mainly it refers to the TRANSPORT thematic area and acknowledges fruitful integration with MANUFUTURE Technology platform. A link should be established with NMP thematic area, and one could with IST, Aeronautic and Space.
These research subjects are coherent with the automotive OEM's standpoint clearly described in the EUCAR position paper of April 7th, 2006.

Elements to be included in the call	State of the Art	Vision / targets	Forecast
Key action 1: Recyclable artificial composites; for example, polymer based nano-composites, in particular for car-body and chassis. Multiscale modeling of structural and functional properties, joining all size scales should be included here. Key action 2: Innovative recyclable material natural based, recycled material employment within the standard production line (supply chain). Key action 3: Coating, multilayers and metal based structured materials (also nanostructuring) to confer new properties (e.g. hardness, tribological, chemical reactivity, etc.) on surface without affecting the bulk material structural properties. Innovative, eco efficient painting/coating which enables new material application. Paintless coloration could be included here. Key action 4: Functionalized textiles for interiors (nanofibers); biocomposite and naturally-based polymeric materials shall be proposed in this frame. Key action 5: Crack-resistant nano-ceramic composites for high toughness applications. Also Metal Matrix materials and advanced metal-polymer-ceramic composites can be investigated in this frame. Key action 6: Carbon fiber reinforced polymers for light-weight applications in the transport industry. Efforts shall be concentrated on increasing material durability and damage tolerance. Key action 7: Virtual-developed foundry technologies for an environment clean efficient machining. Key action 8: New joining techniques and advanced assembling/dismantling processes: new adhesives compatible with oncoming processes; development of technical approaches to integrate new and old materials in the conventional fabrication processes. Key action 9: Protection materials for extreme operation conditions; in particular, carbon based self-passivating materials for high surface temperature (1300°-2000°C) and stress gradients of limited erosion for enhanced thermo-mechanical properties. Key action 10: Multi-material multi-functional integrated solutions for innovative design through a full material exploitation. Key action 11: Improved employment of light weight materials, competitive and reliable manufacturing processes, and new concept application. Key action 12: CO2 emissions reduction, beside costs of exhaust after-treatment systems reduction and energy consumption lowering by: 1)improved surface treatment technologies 2)catalyst innovative materials, e.g. alternative materials to the platinum metals	In order to advance with respect to present materials State of the Art, research needs to focus on really innovative materials and on new concept/way of application to fully enable and stress desired functions, for example lightweight potential. Further, the research, development and manufacturability of this new materials should lead the EU infrastructures forward respect to the emerging not EU competitors. Conventional approaches in material and processes development are helped by new frontier studies represented by the nanosciences; nanotechnologies begin to offer the opportunity to engineer new materials tailored to next generation vehicles although real industrial exploitation remains difficult due to the absence of a validated manufacturing process. Nanotechnologies offer the possibility of make up new materials by assembling building blocks of elementary complex nano-objects (complex means here a material constituted of more than 2 elements), this approach enables the design of artificial superstructures with atomically sharp interfaces with enhanced functionalities. Interesting results will probably be obtained coupling more conventional innovative approaches with radically new processes, like the ones offered by nano-technologies	The vision is joining science and technologies to develop an EU global expertise on materials. In particular, to enhance expertise for product and process design integration to make time to market and process cost competitive with the established ones. Specific targets: • To improve prediction of the final material and of the components made with this material; • To design and build materials having tailored properties (stiffness, strength, hardness, ductility, corrosion resistance, thermal expansion, etc) to fit transport applications using inexpensive manufacturing processes to be scaled up to big volume; • To increase material performances, in particular: lifetime, production rate, reuse and recycling, functionality, to develop production processes of low environmental impact; • To Improve structural functionally graded material for body, chassis and power train applications that could enable different architectural and concept solutions (e.g.. hollow crankshaft, improved lightweight con-rod, structures/sub-assemblies with improved crash worthiness); • To improve dies: lifetime, performance, higher production rate, friction reduction, scrap reduction, used power reduction, functionally induced properties on application, material downsizing through specific coating application, life durable improved lubricant. Components: self scrap protection, self cleaning treatment, improved light emission/transmission; • To promote high conversion efficiency after-treatment systems in all working conditions for a significant scenario change in the actual trade-off between CO2 and pollutant emissions (i.e. lower tailpipe emissions mean today higher fuel consumption for both gasoline and Diesel engines); • To develop new adhesives development and fast curing system. Low or ambient temperature reticulation (compatibility with paintless materials, and with future lower temperature paint process), application system to enhance the global energy consumption; • To apply light weight materials that today are not processable through conventional painting/coating processes; • To develop efficient disassembly, fully recyclable materials, inexpensive recycling re-use processes.	2010-13

EuMaT TOPIC:

3. Nano-assembled-materials enabled components and micro-systems

Brief description of the topic and rationale at a level which you would find in a work program

Nanomaterials with novel electric, magnetic, optical, and mechanical functionalities have been widely demonstrated and are recognized to hold the promise of revolutionizing the way in many fields: health, energy, environment, transportation, space, telecom, etc. Nanotechnologies will push forward frontiers of science and enable the design and the fabrication of new nanostructured and-Nano-Assembled Materials (NAM), NAM-based-components and microsystems both to improve existing applications and to serve new ones today only theorized.

Nowadays, NAMs offer unique opportunities to the EU industries to be competitive by increasing the real and perceived value of their products (improved performances, lower weight and power consumption, added functionalities, etc.) while maintaining or reducing costs for a sustainable growth. Yet, a pre-competitive effort is needed to upscale NAMs fabrication from laboratories to industrial plants; emphasis should be placed on the integration of nanomaterials into macro-scale components and micro-systems by exploiting the broad industrial basis of microtechnologies.

Main development issues and targets at a level which you would find in a work program

The main target of the research proposed is promoting the fabrication of nano-objects such as: nanoparticles (simple and core/shell), nanowires (single element and multilayered), nanotubes, nanolayered stacks, etc., in a systematic way, in order to have nano-objects of monodispersed properties to be used as elementary bricks for NAMs. On these topics, lots of efforts have been spent in the work-frame VI, mainly to study, from a fundamental point of view, physical phenomena happening when matter is confined at nanoscale. The results achieved pave the way to optimism, new phenomena were discovered, systems up to now only theorized were fabricated, but yet lots of efforts have to be spent to reproduce identical systems, a key point to make the most of such a system. In particular, to get this general goal, the following points should be powered:

1. Modeling and design tools for:
   - Complex nano-objects, e.g. core-shell nanoparticles, multilayered nanowires, etc. Physical properties change when matter is nanosized. Particular efforts should be spent to study phenomena at the interfaces of the nano-objects' constituents, e.g. nanoparticle core-shell interface, nanowire layer-to-layer interfaces, etc). Interfacial phenomena play a fundamental role on the NAMs' physical properties both intended for components/micro-systems and for structural materials to serve diverse applications; a fundamental knowledge concerning this subject is limited and should be further explored.
   - Matrices with nano-objects arrays embedded. To envisage the 'effective' properties of NAMs from the properties of their elementary constituents. Modeling should take into account cooperative effects of the single constituents and the role of interfaces between the host matrix and the elementary nano-constituents.
2. Development of the enabling technologies:
   - Fabrication and characterization of nano-objects. The fabrication technologies should be optimized to guarantee a low size and morphology dispersions. The nano-objects shall be characterized in terms of elemental composition, morphology and physical properties. New phenomena are expected to be discovered.
   - Fabrication and characterization of NAMs. Development of techniques to co-deposit host matrices and nano-objects of controlled size and properties. Synthesis in situ of nano-objects in a host matrix and filling of nano-porous templates are also welcome. A goal of this research is to enable the fabrication of NAMs of 'effective' properties uniform over the whole volume.
3. Development of nano-objects and NAMs of improved functionalities to conceive new components and micro-systems for the automotive, biomedicine, energy and the telecom industries.
   - Priorities in automotive: The future advances of the car industry will rely on a further development of existing components and microsystems to serve mainly power train applications. It is acknowledged that either engine or drive train represents tough environment wherein components and micro-systems have to be operated. In this frame, the main target is to develop innovative materials (Nanostructured and Nanoassembled) to upgrade existing devices and improve the vehicle performances. Components have to be operated at high temperature, comply with highly variable operation conditions, vibration and maintain weight, power consumption and unit cost as small as possible. A second priority in the automotive is to develop new NAMs-based-microsystems enabling pluralities of different functions, e.g. sensing, actuation, energy scavenging and communication. Taking into account the components electromagnetic compatibility, the development of high temperature and vibration resistant materials is yet an important step for their final packaging. Important fallouts are expected in the space and industrial robot industries.
   - Priorities in biomedicine: To develop Micro-Fluidic-Systems (MFS) for diseases early diagnosis. The MFSs are thought here as a micro-laboratory wherein biocells tagged by core/shell magnetic nanoparticles or nanowires or light emitting clusters can be investigated by NAMs based sensing elements. In case of magnetic tagging also actuation is possible.
   - Priorities in Energy: To develop new catalysts to increase the conversion efficiencies of fuel cells and biodiesel and to synthesize biodegradable lubricants. New high temperature resistant materials for nuclear reactors, energy micro-generation units for MST energy scavenging and conversion materials for waste energy. To develop new materials from waste (ex. Glycerin)

Expected impact in quantifiable terms at a level which you would find in a work program

The strongest impact of the research proposed is on the automotive context which represents here the main driver. Although, in principle, all automotive components will benefit of the research advances, the most important impact is recognized on the sensor market. Important fallouts are yet expected in emerging fields such as biomedicine. It is generally acknowledged that the vehicles future evolution, to guarantee high efficiency and comply with the restrictive regulations on pollutants emission control, will pass by a close loop adjustment of combustion; to do this, more sophisticated components have to be developed.

Demand for automotive sensors in the North American light vehicle OEM market is increasing of 10.7 percent annually to get $4.5 billion in 2007, comparable figures are expected in Europe by 2010. While automotive sensor demand over the past five years experienced only moderate growth, demand is expected to accelerate rapidly over the next five years, as

multiple new mandated products that prominently feature new sensor applications are rolled out, and as market-driven technology introductions accelerate.
In particular, It is expected:
- Intermetallics for extreme conditions and biomedical applications
- Metal ceramic composites with innovative micro- and nanostructure for multisectoral applications
- Novel materials and technologies for FGM and functional multilayers Intermetallics for extreme conditions and biomedical applications
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- Novel materials and technologies for FGM and functional multilayers Intermetallics for extreme conditions and biomedical applications
- Metal ceramic composites with innovative micro- and nanostructure for multisectoral applications
- Novel materials and technologies for FGM and functional multilayers Low unit cost of components (e.g... a few Euros).
- Take up of the nano-assembly technologies will be developed for high volume production (Forecast 2010).

Sectors addressed:

Automotive sector, bio-industry, telecommunications, space

Required RTD investment: **150 M€ (funding) Integrated project, NOE, Streps**

Implementation priority/justification: Prioritisation within the topics put forward in the SRA of the ETP, taking into account critical dependencies etc.: "1st priority because…. (largest return on RTD investment/prerequisite for further research/etc.)"

1st priority: development of techniques to have nano-objects of the same shape and size (monodispersed morphology);
2nd priority: modeling of NAMs of new physical properties for new generation components;
3rd nano-assembled materials resistant to high temperature, severe thermochemical attack, blasting, corrosion and wearing;
4th priority: nanoassembled materials fabrication – from laboratory to plant.

Notes/comments: e.g. possible coordination needs with other thematic programs

The present research refers to the NMP thematic area and acknowledges fruitful integration with EUCAR and the MANUFUTURE Technology platform, in particular “Transport”. A link could be established with other thematic areas such as: Transport, Lifescience, IST, Aeronautic and Space. These research subjects are coherent with the automotive OEM’s standpoint clearly described in the EUCAR position paper of April 7th, 2006.

Elements to be included in the call	**State of the Art**	**Vision/targets**	**Forecast materialization**
Key action 1: Interfacial phenomena in multilayered nano-assembled materials, in particular multilayered nanowires and thin film stack for sensing and artificial materials development. Key action 2: Development of nano-assembled materials of improved properties with respect to a bulk material commonly used in the context addressed. In particular the research shall be focused on one or more specific targeted properties such as, e.g., weight, elasticity, conductivity, permeability, permittivity, etc. Multiscale modeling and fabrication. Key action 3: Joining new and old materials; in particular, advanced materials for extreme conditions should be integrated into mainstream fabrication processes of components. Key action 4: Nano-assembled coating, multilayered materials and nanostructures to confer new properties on a material surface without affecting the bulk ones; in particular, under the mechanical, tribological and thermal point of view. Key action 5: Nano ceramic composites for advanced engineering applications, in particular components packaging. The design, synthesis and characterization of high-toughness (crack resistant) ceramic nano-composites that retain superior properties at high temperatures. Modeling for life time prediction - through life cycle. Key action 6: Multifunctional molecular and active polymeric materials for sensors, displays and organic semiconductors. Both organic and inorganic elements can be assembled by bottom-up approaches at molecular level to make	Most of components for the automotive industry are today commercially available; however, the restrictive unit-cost constraints of the automotive context reflect the performance limits of products on shelf. Components and micro-systems are mainly based on Si technology. The R&D is mainly focused on Si-compatible materials. Research on new materials mainly concerns a miniaturization of bulks. Top-down and Bottom-up approaches are under development either for nanostructuring or miniaturize. An important lack of fundamental science to envisage physical properties of nano-materials is still acknowledged. Nanostructured materials not only are essential in electronic devices and for densification in ceramics, but also	Modeling and simulation: Development of fundamental physical models to envisage properties of nanoobjects. Definition and calculation of Effective media parameters to describe the nanoassembled materials behavior from properties of constituting nano-elements. Fabrication: Pushing to frontiers of science the fabrication of nano-objects monodispersed in size to discover new phenomena in confined matter. Taking up self-assembly techniques to mass production. The vision is to develop the capability to design and build materials having tailored properties to be used in components and micro-systems using inexpensive manufacturing processes. More in details: • Artificial materials made by in-situ	2010-13

materials of new properties. Key action 7: Ferromagnetic /Ferroelectrics nanoassembled materials for multifunctional devices. Proposal to join the magnetism and ferroelectrics scientific communities. Key action 8: Nano-assembled-materials for MST energy scavenging units; in particular, nanosized magnetostrictive/piezoelectric coupled multilayers. Key action 9: Development of smart nano-assembled-materials of improved performance; in particular: shape memory nanowires embedded in light-weight matrices. Key action 10: Nano-composites light-weight structures with enhanced damping properties and superior damage tolerances; in particular, carbon nanotubes based ones. Key action 11: Magnetic nanowires, nanorods, fine particles and light emitting nanocrystals for biomedical, genomics and proteomics applications. Key action 12: Lightweight bio-composites, in particular, natural fibers in polymers composites. Key action 13: Functional nanomaterials for fuel cell to increase the conversion efficiencies of fuel cells, in particular, within the ranges of catalysts, membranes, which in many cases are critical for the employment of fuel cell technology.	represent a starting point in the formulation of a finished catalyst. Many of the recent advances in materials' synthesis yield materials that their primary grain sizes are a few nanometers. Properties of materials of nanometric dimensions are significantly different from those of atoms as well as those of bulk materials. Suitable control of the properties of nanometer-scale structures can lead to new sciences as well as new devices and technologies.	synthesis of micro- and nanoparticles in light weight matrices; • Core-shell particles (also nanoparticles) synthesis e desegregation; • Nanostructures passivating coatings and nanostructures self-assembly; • Nanostructures manipulation; • Complex electrodeposition of multilayered nanowires in light-weight matrices; • Low roughness interfaces by pulsed electrodeposition to fabricate multilayered stack in porous templates; • Wear resistance at nanoscale • Self organization of nano-particles during synthesis.	

EuMaT TOPIC:

4. Direct and Inverse Advanced Engineering Materials design through Integrated Multiscale Collaborative Frameworks

Brief description of the topic and rationale at a level which you would find in a work program

In the European Technology Platform for Advanced Engineering Materials and Technologies (EuMaT), multiscale modeling and simulation is considered as a "Horizontal Issue" which informs is functional to all the key Pillars (Knowledge-based Multifunctional Materials, Materials for Extreme Environments, Hybrid & MultiMaterials). The proposed "Integrated Multiscale Collaborative Frameworks" represent a new frontier for multiscale, for the improvement of existing Engineering Materials and Technologies and for the design, development and application of New Generations of Nanostructured Materials, and Nanotechnologies including the future nanobased Material. This new kind of Frameworks allows, for the first time, to take into account, inside a unified context, all the phenomena, from atomic and molecular scales to the engineering ones which rule materials design, processing and application including life-cycle and sustainability issues. Integration of atomic/molecular scales, typical of nanoscience, with the micro, meso and macro worlds is a fundamental challenge for a wide industrial application of the most innovative nanotechnologies in the materials, engineering and processing areas. Integrated Multiscale Collaborative Frameworks realize a real "two-way" science-engineering integration from an industrial point of view and put the bases to create a new ***"Multiscale Quantum (Nano) Engineering World".***

Key features of the new Frameworks

- **New Industrial Development Strategies :** New Frameworks allow to integrate the classic "Direct" or "Bottom-Up" R&D approach (from basics to engineering, processing and performance requirements) with a new "Inverse" or "Top-Down" strategy (from performance requirements to fundamentals) leading to a really **"Science-based Industry Driven"** technology and materials development strategy. Frameworks output is directly applicable to industrial design problems. The Multiscale strategy leads to engineering models with increased predictive capabilities and reliability and a significantly reduced number of adjustable parameters. Models are "science-based", but directly usable by designers not necessarily by scientists.
- **Integrated Engineering Strategies Modeling and Characterization:** a key industrial challenge for a cost effective development and production of both traditional and innovative Nanomaterials is the integration of computational modeling with experimental and testing techniques. Integrated Multiscale Collaborative Frameworks enable real unified modeling - experimental & testing strategies thanks to the "Multiscale Information Space" concept and method
- **"System Engineering" Strategies :** New Frameworks enable also an easier integration of advanced materials and devices into systems (Multiscale System Engineering approach) by taking into account the full spectrum of interactions among devices, components and systems.

The proposed Frameworks synthesize in an <u>innovative way</u> experiences and achievements the most advanced trends and challenges of US and Japanese programs on the field of advanced material technology and directly incorporate a wide spectrum of existing computational models and methods with limited modifications enabling so affordable development costs, times and risks.

Integrated Multiscale Collaborative Frameworks are a comprehensive and coherent expression of the key themes and issues addressed by EuMaT Strategic Research Agenda: New Frameworks position themselves as an essential horizontal resource for all the Clusters and Application Areas envisaged by EuMaT such as Knowledge-based Multifunctional Materials, Extramat and Hybrid Materials Biomaterials and , including all the emerging and future Nanomaterial, Nanoprocessing and Nanotechnology fields in key Areas for Europe and European Industry like Energy, Electronics, Aeronautics, Automotive, Space, Bio-Medicine and Civil Engineering.

Main development issues and targets at a level which you would find in a work program

The key target of the proposed research area is the ***Development of new "Integrated Multiscale Collaborative Frameworks"*** as an enabling "Horizontal" resource and integrated tool to be *<u>directly</u>* applied to the design and development of materials and devices and related processing techniques in all the application clusters and areas foreseen by EuMaT. Direct application is fundamental both for validation and as a key driver for a continuous tuning and improvement of the Frameworks. It is a "two-way" link.

Application experiences are a fundamental driver to improve both the overall Framework Architecture and the Framework Components (multiscale models and methods, multiscale data bases, multiscale visualization software). At the same time, "Integrated Multiscale Collaborative Frameworks" directly take advantage of and drive scientific advances in a wide range of research fields. They offer a context were research advances in different fields can be integrated and applied to industrial problems in a reduced time and cost framework (key issues for Nanotechnology). New Frameworks realize a synergistic integration between a "Science-driven Engineering" and an "Engineering-driven Science" approach whose most striking symbol is Nanotechnology.

Main elements of the Framework running on "Virtual Distributed Environments (Cyberinfrastructures)":

- Languages and Modules to describe physical and chemical structures and related Structure – Properties – Performance – Processes relationships and interdependencies over the full range of space and time scales.
- Steering (or Strategy) Module to define different strategies to integrate over a full spectrum of space and time scales different sets and sequences of analytical, computational and experimental & testing techniques and methods
- Library of Analytical, Computational and Experimental & Testing Models, Methods and Techniques and related Multiscale methods to correlate and integrate them over a wide range of different (space and time) scales. A key feature which distinguishes the proposed Framework from other existing advanced Frameworks, is its ability of integrating, inside a coherent and unified strategy, computational and experimental & testing techniques and methods thanks to the "Multiscale Information Space" concept
- Modules tailored to address specific design tasks and issues like dynamics, durability, manufacturability, environmental degradation
- Multiscale Data and Knowledge Analysis and Management Module
- Multiscale Visualization Modules

Expected impact in quantifiable terms at a level which you would find in a work program

The lack of well integrated European-wide initiatives in this new Area is a very high priority and it is the basic motivation which underlies the proposed research. Europe has the occasion to take the lead in these strategic fields and EuMaT is a real opportunity to do that. Accordingly, *the fundamental goal of Integrated Multiscale Collaborative Frameworks is to produce real industrial and technological breakthroughs, not simple evolutionary improvements.*

Specific expected benefits:

- Intermetallics for extreme conditions and biomedical applications
- Metal ceramic composites with innovative micro- and nanostructure for multisectoral applications
- Novel materials and technologies for FGM and functional multilayers Reducing development, maturation and application times for innovative nanostructured material developments
- Reducing Development Risks (Failure Probability) for highly innovative projects by significantly get the dimension of the so called “Valley of Death” down and Increase confidence in the material final performance
- Improved Flexibility in nanostructured material design and tailoring possibilities
- Reduced raw material consumption and energy requirements
- Promoting a wide adoption by Industry of the “Green by Design” approach as opposed to the traditional “Waste Management” strategy. Taking the lead in the “Industrial Green by Design” sector would give EU industry a strategic competitive edge over US and Asian competitors (Japan, Korea, China and India).

Sectors addressed:

Integrated Multiscale Collaborative Frameworks are inherently cross disciplinary and cross sectoral. Accordingly, they can be of primary relevance for a wide range of sectors: Aeronautics, Automotive, Electronics & Photonics, Biomedicine, Chemistry and Biochemistry, Energy, Space, Security

***Required RTD investment:* 150 M€ (funding) small and large projects, NoE**

Implementation priority/justification: Prioritisation within the topics put forward in the SRA of the ETP, taking into account critical dependencies etc.: "1st priority because…. (largest return on RTD investment/prerequisite for further research/etc.)"

1st priority: design and development of the new Integrated Multiscale Collaborative Frameworks
2nd priority: setting up application programs which apply this new kind of Frameworks to a wide range of highly innovative industrial materials & processing programs.
3rd priority: establishing direct links between the Application and the Framework development worlds
4th priority: design and development of Educational Frameworks and related specific programs and initiatives

Notes/comments: e.g. possible coordination needs with other thematic programs

A distinguishing feature of the proposed research is that it concerns all the areas where traditional as well as new advanced Nano materials and processes play a key role: NMP, Aeronautics, Space, Energy, Transport, Electronics, and BioMedicine. Furthermore, “Integrated Multiscale Collaborative Frameworks are a strategic driver for a wide spectrum of the Computing, Information and Communication areas (IST) (new modeling and simulation software, multiscale data analysis and management systems, visualization systems and techniques).

Elements to be included in the call	**State of the Art**	**Vision/targets**	**Fore-cast**
Key action 1: Design and development of **Integrated Multiscale Collaborative Frameworks** for Materials, Devices and Processes Design, Development and Testing running on Cyberinfrastructural Environments. This action will include the definition of the general Architecture, Functional and Application Areas, Best Application Practices and Strategies, Validation Strategies for the Frameworks and related Cyberinfrastructural Environment and the definition of the architectural characteristics, performance, functional and application areas of the Framework components. These frameworks will be extended to be applied to specific “System Engineering” Issues. The validation of the Frameworks will be carried out through specific **Application-oriented** projects approaches. Key action 2: Design, development and validation of the Framework Components running on Cyberinfrastructures with a special emphasis on the design, development and validation of : • New Generation of Languages Models and Environments to	A very large number of European and International Research Centers are developing activities which are focused on the design, development and the application of computational multiscale methods both in the traditional Materials Engineering and Processing Area and in the Innovative one (Nanomaterials and Nano-processing). Computational Multiscale is applied inside European industry to address Material design and development issues with particular reference to sectors such as defense, energy and chemistry. As far as the International Scenario is concerned, three factors are characterizing US and Japanese Programs : 1. the average dimension of the initiatives and programs is normally higher than the correspondent European ones 2. the development of true Integrated Collaborative Multiscale Frameworks 3. the close integration, inside long term cooperation contexts, of University – Research – Industry and the application of the new “Industrial paradigm” application –driven (top – down) for technology development A single “Integrated Multiscale Collaborative Framework” can be conceived to be applied to a more or less wide spectrum of Material Areas and Issues. The US DoD AIM-C Program (led by Boeing) focuses on Composites. The “Structuring Knowledge” Project led by University of Tokyo and funded by METI (Ministry of Economy, Trade and	Targets: ***a New Generation of Systems, Methods and Techniques:*** • Integrated Collaborative Frameworks for Materials, Devices and Processes Design, Development and Testing [SW] • Multiscale Experimental & Testing Technologies, Systems and Environments [HW and SW] • Multiscale Data and Knowledge Analysis and Management Systems [SW] • Multiscale Visualization Systems [SW] • Multiscale Modeling and	3-10 years

describe physical and chemical structures and related Structure – Properties – Performance – Processes relationships and interdependencies over the full range of space and time scales. • Integrated Multiscale Steering (Strategy) Methods and Environments which allow to develop Integrated Multiscale and Multi Methodological (integration of analytical, computational and experimental & testing methods and techniques) Science-Engineering (Top-Down and Bottom-Up) Strategies for the design (including life-cycle and sustainability issues), development, testing of new materials, devices, components and related processing/production technologies and techniques. • Multiscale Data Analysis Integration and Management Methods and Environments which will apply the Property, Structure, Performance, Processing relationships over a full range of scales (Top-Down and Bottom-Up strategies) to correlate data coming from different multiscale design and testing strategies resorting to a full range of different methodologies (analytical, computational, experimental & testing). . Integrated correlations will lead to an “Integrated Knowledge-based Vision” of Materials Characteristics and Performance, Processing, Life-Cycle and Sustainability Issues and of all the aspects characterizing the whole design, development and testing cycle. • Multiscale Visualization Methods and Environments • A New Generation of Multiscale Computational and Experimental & Testing Methods and related Integration methods (multiscale multi-methodological approach) aiming to generate the needed amount of knowledge and information to be supplied to run the models and modules. Key action 3: Design, development and validation of a New Generation of Educational Courses which incorporates the basic principles and paradigms embedded in the Integrated Multiscale Collaborative Frameworks. The new courses will be based on specific “Multiscale Collaborative Educational Frameworks” which will take full advantage of new Multiscale Visualization, and Data Analysis and Knowledge Management Modules developed in the context of the Integrated Multiscale Collaborative Framework projects.	Industry) is an Integrated Multiscale Collaborative Framework conceived to be a “Horizontal” platform for the whole Nanomaterial Japanese Project constituted by eight specific projects (nanoceramics, nanometals, nanocomposites...). Different Integrated Frameworks, more or less focused, are, anyway, characterized by a large degree of commonalty. Some examples of US and Japanese Multiscale Collaborative Framework Programs in the traditional Materials Area and in the Innovative one (Nanotechnology) • **Computational Material Design Facility (CMDF) – Caltech** CMDF developed an “Integrated Multiscale Computational Framework” for the design of Complex Materials, Chemical and Biological Systems. It foresees both the classical (bottom-up: from science to engineering) paradigm and the novel one (Inverse or application – driven that implies identifying new structural combinations of materials capable of providing desired properties). The Framework is currently applied to the development of innovative (nanostructured) materials. Example: Hierarchical Design for Predicting Real Optimized Materials Program (PROM) – Thermoelectric materials – Thin film ferroelectrics – Non-linear optical materials – High Energy Density Materials • **NSF Center for Computational Materials Design (CCMD)** – Georgia Tech and Penn State University. Besides these universities CCMD has several members coming from research Centers and Industries: Air Force Research Lab, Army Research Lab, Auraryd, Corning, GE, General Motors, Knolls Atomic Power Lab, Lawrence Livermore National Lab, Los Alamos National Laboratory, nGimat, Pratt &Whitney, ThermoCalc, and Timken. Focus Areas : Multifunctional Structural Materials and Nanomaterials & Nano to Micro Devices Key Issues – integration of multiscale computational modeling with systems – based engineering. – physics - based simulation of : process – structure - property relations – digital interfaces to facilitate collaborative, distributed decision - based design. • **Structuring Knowledge Project in Nanotechnology Materials Program**: Construction of a Knowledge Infrastructure (Framework) for Nano-materials and Devices. The Program is managed by The University of Tokyo and funded by METI (Ministry of Economy, Trade, and Industry). Japanese Government launched a large long term Nanomaterials National Program constituted by eight (8) Specific Application Oriented Projects and by a special Project named “Structuring Knowledge (SK)”. The objective of the SK Project is to develop an “Integrated Multiscale Science - Engineering Platform (Framework)” named “Nanomaterial Platform” to design innovative Nanomaterials and to systematize knowledge gained inside the several application-oriented projects. SK uses a “Knowledge System” which correlates data and information by applying the “Process – Property – Structure” relationships strategy. This System is an interesting application of the new (top-down or application-driven) Industrial Paradigm for materials technology development and a clear demonstration of the new “Strategic” Frontiers opened by “Integrated Multiscale Collaborative Frameworks”.	Simulation Tools to address Design (Materials, Devices, Components and Processes), Testing, Life-Cycle and Environmental issues [SW] • Multiscale Educational Courses and Environments [SW]	

EuMaT TOPIC:

5. Novel multifunctional materials for multisectoral applications in highly demanding operational conditions

- **Intermetallics for extreme conditions and biomedical applications**
- **Metal ceramic composites with innovative micro- and nanostructure for multisectoral applications**
- **Novel materials and technologies for FGM and functional multilayers**

Brief description of the topic and rationale at a level which you would find in a work program

INTRODUCTION. The proposed topic addresses a class of knowledge-based multifunctional materials (shortly *KMM*) combining metallic and/or ceramic multi-components tailored for durable and safe performance in multisectoral applications. The topic is of strategic importance for Europe as it belongs to the forefront of the materials research worldwide with prospective impact on many sectors of European industry. Importantly, it emphasizes the issue of cost-effective production routes while not compromising on enhanced material properties as these are needed in highly demanding service conditions. The topic should be treated within EuMaT, a cross cutting European technology platform, due to versatility of the *KMM* in different industry sectors on one hand and the proposed methodology, advocating integrated problem-oriented approach, on the other. This *KMM* methodology is comprehensive in the sense that it spans processing, characterization, modeling, and assessment of the produced elements (in industrial environment of the end-users). As a consequence, multipartner task forces with different expertise will have to be formed to tackle research problems suggested by the EuMaT industry members. To this end, EuMaT offers a convenient platform for direct two-way interaction between research and industry partners. Somewhere along the line, as the research work progresses, the horizontal character of the proposed *KMM* topic may well get focused on some specific applications. Therefore, it is highly desirable to establish close ties with other technology platforms dealing with specific sectors/applications in order to combine the research effort, exchange of experience and disseminate the results obtained. The proposed topic is concerned with three main groups of advanced materials: Intermetallics, Metal Ceramic Composites, Functionally Graded Materials and Functional Layers.

Intermetallics offer a compromise between metallic and ceramic properties. As aluminides (TiAl, NiAl, FeAl, etc) retain a high specific stiffness and tensile strength at temperatures up to 700°C-900°C and have superior corrosion resistance relative to stainless steels, also in sulfur-containing environments, they are and can be further tailored to applications in aerospace, automotive, chemical and fossil fuel industries. Smart intermetallics (NiTi, Cu-based and Fe-based intermetallics) found large number of applications in biomedical devices, aircrafts, fasteners, sensors, etc. However, increase in commercial usage of intermetallics is inhibited by their poor ductility and toughness at room temperature what causes difficulties in manufacturing and generates high cost of processing. Though intensive studies over the last decades brought the solutions for the most drawbacks there is a need for further R&D devoted to wider and most effective usage of these advanced materials in EU industry.

Metal Ceramic Composites with novel mechanical, electric, thermal and magnetic functionalities are recognized to hold the promise of revolutionizing the several technological fields: including energy, environment, transportation, space, telecommunications and healthcare. A great variety of metal ceramic composites with designed micro- and nanostructure, including particle reinforced and fiber reinforced materials, as well as nanostructured and laminate composites, will enable the design and the fabrication of new multifunctional and structural components for durable and safer performance enabling both to expand their use in existing applications and to materialize new uses in yet unexplored fields. Novel metal ceramic composites are materials offering unique opportunities to EU industry to be competitive by increasing the added value of manufactured products (improved performance, higher durability, lower weight and energy consumption, multiple functionalities, etc.) while being an integrated part of a sustainable growth strategy. Several aspects of metal ceramic composites development require further R&D emphasis, which include micro- and nanostructure characterization, influence of processing on micro- and nanostructure, modeling of micro-cracking, fracture and fatigue, defect kinetics and creep mechanisms, modeling of micro-macro transitions as well as assessment of industrial needs and applications.

Functionally Graded Materials (FGM) and **Functional Multilayers.** Functionally graded materials (e.g. Bio-FGM, piezoelectric FGM) and functional multilayers are increasingly conquering large market shares. The Bio-FGM offer enormous possibilities for substitution or repair of lost tissue function. The performance of such materials is validated through a number of physical, chemical, and biological tests as well as in animal or clinical studies. However, finding of new or improvement of existing processing routes, as well as employment of tissue engineering scaffolds in various clinical and biological settings is largely done in a trial-and-error procedure. Alternatives such as theory-supported material design are hardly existent for biomaterials. The key issue in biomaterials design is the interface between man-made material and biological environment (i.e. tissue). Therefore, theory-based understanding of the functioning of biological materials beyond the well-established chemical characterization and visualization would offer enormous possibilities for technological progress in tissue engineering, a key topic in economically strong, but aging societies such as encountered in the EU.

Prominent examples of functional multilayers' application are multilayer actuators, multilayer sensors, and multilayer semiconducting devices. For example, Europe is leading in the technology of multilayer actuators, a field with triple-digit growth rates. However, the actuators are based on lead-containing compounds. Strong research investments, mainly in Japan threaten the current leadership position. Research in the development of novel lead-free piezoceramics is therefore very much in demand. This research should include ab-initio modeling of feasible substances, processing of multi-component materials and advanced structural research. Input from materials science, chemistry, physics and mechanics is required. Another example lies in the field of semiconducting ceramic multilayers. Ceramic multilayers can be printed and maintain a higher reliability as compared to semiconducting polymers. However, preparation of semiconducting ceramics, including their doping and their control of defect states at interfaces is barely available. Monolithic ceramics with continuously varying chemical composition show, after poling, an inhomogeneous distribution of dielectric and piezoelectric properties. A similar effect may be achieved with a constant chemical composition and an inhomogeneous poling field. Such functional gradient materials especially are suitable for bending actuators e.g. in bimorph layered systems. Advantages are low internal stresses, low production costs and the possibility to design systems from materials which are lead-free. Huge financial profits loom on the horizon in the field of printed electronics. In this field, Europe has the best starting point, as it controls more than 70 % of the world-wide market of printing machines. Thereby, collaboration between mechanical engineering and electrical engineering with materials science, physics and chemistry would make it possible to gain and strongly secure the leading market position.

Main development issues and targets at a level which you would find in a work program

Intermetallics. The main target of the research is establishment of the reliable knowledge and know-how databases on intermetallics that encourage the community of European designers to widespread the use of intermetallics as well as the assessment of the real alternative to conventionally used materials in view of the reduced total life-cycle costs. It will also lead to EU expertise on these materials. To achieve this general target the following issues should be tackled:

1. *Improvements of properties and controlling the microstructure in order to achieve multifunctional materials*
   The ductility and strength of aluminides is controlled by chemistry (the alloys used and their composition) and material microstructure. Alloying elements increase ductility at room temperature and improve resistance to oxidation and creep strength at high temperature that is especially important if long-term service is considered. They also cause the grain refinement. Material microstructure affects significantly material properties, for example, in case of titanium aluminides development of the lamellar microstructure changes their properties in view of fracture toughness, creep resistance, tensile ductility and strength. Microstructure is controlled by the proper processing. Further researches on the relations between properties and microstructure as well as microstructure – processing technology are clearly needed. The important issue is also the stability of the obtained microstructures as far as life-cycle reliability is concerned. In the area of shape memory alloys (SMA) research on properties and microstructure should lead to improvement of bio-performance and bio-compatibility as well as development of the alloy composition with reduced amount of possibly cytotoxic elements (e.g. Ni)

2. *Establishment of reliable property database as well as characterization and modeling standards with the aim to encourage the EU designers to replace the traditional materials by intermetallics*
   It is observed that unsatisfactory usage of intermetallics is caused by the lack of reliable databases concerning the properties of intermetallics. This creates the need to develop characterization techniques together with their standardization. There is also much research needed in the field of modeling, specifically prediction of material behavior and properties with account for micromechanics, multiscale analysis in inelastic range permanently enhanced by the increasing power of computers, analytical modeling of fracture and creep processes.

3. *Transfer of developed new processing technologies from laboratories to commercial production*
   Industry appears to be on the threshold of significant use of intermetallic materials for light-weight elements. There are many traditional and novel techniques belonging to ingot metallurgy and powder metallurgy developed to process intermetallics: routes based on massive transformation, SHS route, mechanical alloying and hot isostatic compaction, powder metallurgy based on reactive sintering etc. Some of them have been already applied on industry scale. However, for wide-spread applications it must be shown that semi-finished products and components with specified properties can be manufactured in large quantities at reasonable costs. For structural applications appropriate joining and repairing techniques must be available which guarantee processing of reliable joints exhibiting good mechanical properties especially at temperatures below brittle-to-ductile transition. For the application of SMA intermetallics, proper surface processing techniques should be developed to achieve better bio-performance, also processing methods should be improved towards cleaner, more efficient precise alloying with reduced waste as well as integration of multifunctional properties of SMA to form smart elements (e. g. self-repairing one)

4. *Identification and exploration of new potential areas of applications*
   Aluminides are expected in the future to be used as components in high-speed aircrafts, also in aerospace advanced engines (TiAl) and in chemical or fossil fuel industries, they probably will find (FeAl/Fe3Al, NiAl/Ni_3Al) application in air deflectors for burning high-sulfur coal, ethylene crackers, coatings for oil drilling components, coal burners, in high field and large-scale magnet applications e.g. coils in thermonuclear reactors (Nb_3Al, Nb_3Sn). There should be also a research effort undertaken in the area of smart intermetallics devoted to their further applications in medicine and industry taking the advantage of their interesting properties e.g. magnetic shape memory effect. Other possible applications of intermetallic materials may be as matrix material for metal matrix composites and as thin films and intermetallic layers serving as coatings on metal substrates containing intermetallic forming elements and enhancing performance of elements under harsh in-service conditions.

Metal Ceramic Composites. The main target of the research proposed is to promote the fabrication and characterization of metal ceramic composites with innovative micro- and nanostructures. Great effort on related topics was spent in FP6 to integrate research activities on materials science, solid mechanics and manufacturing technologies in the field of metal ceramic composites. A comprehensive literature survey was performed and the areas in need of further research related to metal ceramic composites were identified. In particular, to achieve the goals enumerated above, the following aspects should be targeted:

1. *Microstructure characterization*
   - Understanding of interfacial fracture and its relation to processing.
   - Knowledge of properties at elevated temperatures, relating to crack propagation, cyclic and slow crack growth, oxidation, and corrosion and wear.
   - Determination and evaluation of properties under operational conditions, e.g. regimes of temperature, static and dynamic loading, atmospheric and other operational media.
   - Increase understanding of the relationship of properties to microstructure, with special regard to statistics (scatter), microstructural morphology, processing and modeling.

2. *Influence of processing on microstructure*
   - Use of highly purified starting materials which have a strong effect on the structure and composition of the interfaces and on the evolution of the microstructure.
   - Densification kinetics of ceramic matrices containing particle inclusions. Prediction of final part shape and dimensions from data of the “green” bodies.
   - Influence of nanoparticles on the mechanical properties of the composites
   - Cost/performance ratio of new (nanostructured) products has to be optimized and the reliability of the products improved.
   - Improved cost-effective processing methods; influence of process parameters on properties is paramount.
   - Developments in coatings of fibers to improve wettability.
   - Development of new cost competitive matrix/reinforcements combinations.
   - Reliable methods for processing nanocomposites of relevant dimensions and shapes

3. *Modeling of micro-cracking, fracture, friction, corrosion and fatigue*
    - Modeling realistic (with random variations) distributions of particles in CMC.
    - Inclusion of surface/interface effects at nano-scale.
    - Modeling of debonding and cavitation effects.
    - Multiscale modeling including realistic microstructure.
    - Reliable test data on interfacial properties.
    - Modeling of stress transfer between phases in interpenetrating CMC.
    - Consideration of residual stress field in crack growth modeling.
    - Multiscale techniques for developing interfacial and damaged matrix constitutive relations in nano-particle/nano-tube CMC.
    - General improvement in simulation techniques at nano-scale.
    - Improved methods relating CMC and bimaterial microstructure to fatigue growth phenomena.

4. *Defect kinetics and creep*
    - Light weight metal matrix composites with stable and strong metal-ceramic interface leading to improved properties at elevated temperature.
    - Modern non-destructive testing methods to improve the understanding of creep or corrosion damage. Combination of such methods with suitable fatigue models for CMC for improved prediction of the fatigue remnant life of components.
    - Creep and fatigue data for complex loads (which prevail in real applications). Tests under multiaxial loading.
    - Investigations concerning plasticity-creep interactions in CMC even for uniaxial stress state.
    - Information on creep, corrosion, fatigue and reliability behavior of CMC with interpenetrating network microstructures.
    - Long-term durability of fiber reinforced CMC at elevated temperatures: (1) creep and rupture of the fibers, (2) environmental degradation of the constituents. Creep properties of oxide fibers (.e.g. by recrystallization) and stability of interfaces as breakthrough for CMC applications in demanding environmental conditions.
    - Creep, corrosion characteristics and damage mechanisms of laminates. New concepts to enhance creep and fatigue properties of metal ceramic composites. Performance of layered ceramic matrix composites in the transverse direction.

5. *Micro-macro transition, multiscale modeling effective properties*
    - Multiscale modeling techniques to cover ab-initio dynamics, atomistic simulation and macroscopic analysis.
    - Reliable techniques for modeling the complete production process.

6. *Industrial needs*
    - New cost competitive reinforcements to avoid the use of high-cost base materials.
    - Development of non-Al composites for higher performance.
    - Near-net-shape production routes to cut cost of secondary processes, e.g. machining, finishing, and welding.
    - Development of new MMC and CMC systems with high ductility, toughness and corrosion resistance.
    - Development of NDT concepts for the specific features of MMC and CMC.
    - Interphase materials, for stable CMC at temperatures in the range 1200-1500°C.
    - Improved reliability of CMC.
    - Development of low cost and flexible production routes, e.g. those based on the gas phase.
    - Improved understandings of the oxidation, creep, wear and fatigue resistance of CMC.

FGM and Functional Multilayers.
The key research challenge in Bio-FGM is the identification of ‘universal’ material properties of elementary building blocks inherent to whole classes of Bio-FGM, as well as universal pattern of interaction they obey over various observation scales. Such material properties are of mechanical, physical, or chemical nature, they are related to material volumes or interfaces at a suitable observation scale. They would allow for ‘translation’ of chemical into mechanical/physical information or vice versa, in a unified setting. The identified properties of the elementary bricks used in nature would define clear structure/function/property-requirements to be met by the biomaterial to repair the lost tissue function. Therefore, identification of micro and nanostructure mechanics and physics of biological materials is expected to lead new, more precise ways in biomaterials design for repair of lost tissue function, replacing a trial-and-error procedure by a truly engineering-science based approach. This would significantly enhance applicability, security, and economy of tissue engineering solutions.
In functional multilayers and piezoelectric FGM there are two main targets to be approached: Development of novel materials and development of novel technologies as suitable for mass production, which includes knowledge of high-reliability technologies.

1. *Development of new materials for actuators:*
    - New actuator materials need to work without additions of lead and other toxic elements. Several crystallographic systems are yet only marginally explored. Most promising appear combinations of perowskites based on Bismuth, Niobium, Titanium and Tantalum. As perowskites show high solid solubility, many opportunities arise.
    - New actuator materials can be developed using ab-initio computations to aid in the search for new materials. Current computational methods and computer power is just at the verge of being useful to develop new functional materials based on atomic building blocks. Density functional theory for virtual atoms or by using large super-cells has shown the first useful results. These techniques need to be developed further to help the development of cost-efficient material through simulation techniques.

2. *Development of new materials for semiconductor applications:*
    - Printed electronics requires p- and n-doped semiconductors, where printing ceramics can offer new markets in the form of radio frequency identification (RFID). The ceramics envisaged are based on several oxide systems with different options for doping. The materials require dispersion as a printable medium and curing at low temperature on a variety of substrates.
    - Fabrication of printable electronics requires development of new technologies for printing and concurrently adaptation of design of the electronics circuits. Therefore, modeling of current flow and defect states is very much in demand.

3. *Development of multilayers for a wide range of applications:*
    - Priorities in motion control: Motion control is a vast future field which describes the ability to move small components and medium-sized components at frequencies up to 100 kHz and with a precision of less than 1 micron, at the same time with a stress resilience of several MPa at least. Naturally, motion control is required in the car for small motors (e.g. piezomotors for air ventilation, but also piezoinjectors for superior fuel control). Motion control, however, is required in many more other technologies. Amongst these are: textile technology, printing technology and high precision movements in the microtechnology industry as well as space industry.
    - Priorities in Biomedicine: Sensors and actuators are required for efficient control and support of many bodily functions. Amongst these are sensing of pressure and temperature. Also, for stabilization of key functions, drug delivery using small actuators may be warranted, which may be activated on prior sensing facility.
    - Priorities in Communication: Communication with radio identification techniques is one of the biggest markets for the future. Identification tags based on printing technology are required to provide costs in the area of less than 5 cents per product.

Expected impact in quantifiable terms at a level which you would find in a work program

Intermetallics. Their properties and development/improvement of processing methods will enable:

- the automotive industry to improve efficiency (reduced fuel consumption, pollution, and costs) and safety (e.g. noise level) due to high specific stiffness of intermetallics
- the chemistry and fossil fuel industry to develop elements of mixed material structure with high corrosion and erosion resistance extending their life cycles and thus reducing the total life costs
- generation and exploration of new possible areas of application in medicine as far as shape memory effect is considered
- the transfer of novel manufacturing processes to automotive, aerospace and biomedical industries.

Metal Ceramic Composites. The strongest impact of the research proposed is on transportation, energy, environment and to a less extent healthcare and telecommunications

FGM and Functional Multilayers. As for expected impact of Bio-FGM, the costs resulting from lost, injured, or diseased tissue are hard to estimate, but already single diseases responsible for tissue injury, such as osteoporosis, result in enormous costs (31.7 billion € in 2000 in Europe). Thus, any improvement in the production process or in service life quality of tissue implants or scaffolds, such as reduction of prosthesis decay and rejection, and of costs of hospitals for replacement of prosthesis will have a strong impact on European societies. On the level of an individual, the cost for medical devices would fall, making them available for the majority of the population and alleviating the burden on European social security systems.

As for functional multilayers, the two main fields considered here are the actuator and the semiconductor technology. Piezo-injectors currently grow with a growth rate of more than 100% in Europe and add several thousand new jobs every year. It is expected that the area of printed electronics will develop to a similar new market field.

Sectors addressed:

Intermetallics: Automotive and aerospace sector, chemical, fossil fuel industries, biomedical sector
Metal Ceramic Composites: Transport, energy conversion systems, environment and sustainable development, telecommunication, healthcare
FGM and Functional Multilayers: Bio-industry, medical system; bio-medicine and drug delivery, automotive sector, textile industry, telecommunication

***Required RTD investment:* 450 M€ (funding) - Collaborative Projects**

Implementation priority/justification: Prioritisation within the topics put forward in the SRA of the ETP, taking into account critical dependencies etc.: "1st priority because…. (largest return on RTD investment/prerequisite for further research/etc.)"

Intermetallics
1st priority: Development of intermetallic materials for high speed vehicles engines through weight reduction
2nd priority: Development of intermetallic materials of new physical properties for new functions
3rd priority: Take up of the intermetallic materials fabrication processes – from laboratory to industry
4th priority: Intermetallic materials resistant to high temperature and serving as corrosion and erosion resistant coating

Metal ceramic composites
1st priority: Development of processing techniques to reliable production of metal ceramic composites with tailored micro- or nanostructure
2nd priority: Modeling of metal ceramic composites exhibiting multiple functional properties and structural integrity for new generation components
3rd priority: Measurement of relevant mechanical and functional properties
4th priority: Design and fabrication of components of real shape and dimensions exhibiting resistance to high temperature and stresses, severe environmental attack, abrasion and wear

FGM and Functional Multilayers
1st priority: Development of lead-free piezoelectric materials
2nd priority: Development of ceramic doped semiconductors
3rd priority: Development of multilayer technology (including electrodes, poling, etc.) for new piezoceramics; development of printing technology for cost-efficient RFID
4th priority: Tailoring of biomaterials based on mechanical/physical/chemical identification and characterization of universal elementary constituents through combined experimental-analytical-numerical approach – theory supported transdisciplinary tissue engineering

Notes/comments: e.g. possible coordination needs with other thematic programs

Elements to be included in the call	State of the Art	Vision/targets	Forecast materialization
Intermetallics Key action 1: Titanium aluminides for room and high temperature application in the automotive and aerospace industry. Micromechanical and multiscale modeling should be here included allowing understanding of microstructure and its stability – properties relationship. Key action 2: FeAl for intermediate temperature application where its remarkable oxidation and sulfidation resistance is important. Key action 3: NiAl as structural material of high strength at elevated temperature Key action 4: Exploration of Nb_3Al and Nb_3Sn as candidates for electromagnet applications due to their super-conducting properties Key action 5: SMA intermetallics investigation in biomedical applications, enhancing their performance and reducing cytotoxicity. Analytical (phenomenological) and micromechanical modeling of shape memory materials should be here included Key action 6: Exploration of possible areas of application of magnetic shape memory alloys (NiMaGa, Fe-Pd, Fe-Pt) Key action 7: Intermetallics as matrix materials in metal matrix composites Key action 8: Intermetallics in mixed material structure: intermetallic thin films and layers	**Intermetallics** • The observed interest in intermetallics as light-weight materials has been driven during last decade by titanium aluminides and R&D progressed significantly. They have led to better understanding of fundamental influence of alloy composition and microstructure, relative to mechanical properties and processing behavior. It has been shown that they can be processed using conventional metallurgical methods. However, these materials still require characterization relative to their behavior in extreme conditions (high temperature, dynamic loading) and enhancing efficiency of processing technology • Major problems of SMA intermetallics concerning manufacturing techniques and thermo-mechanical treatment have been already tackled. A research effort is now directed to improving existing technologies, development of reliable standardized characterization techniques, exploration of new SM effects and new SMA among intermetallics • As for FeAl, NiAl with their high corrosion resistance and intermetallics presenting super-conducting properties, the database on properties and modeling of this materials is rather limited and extensive research are needed to accelerate increase the use in commercial application of these materials	**Intermetallics** The vision is joining science and technologies to develop an EU global expertise on advanced materials. In particular, to establish expertise for product and process design in terms of characterization and modeling standards to make time to market and process cost competitive with state of the art solutions. Specific targets are: • to develop intermetallics characterization techniques allowing procedures for standardization • to achieve reliable property database for intermetallics • to develop, on the basis of micromechanics and multiscale modeling, the methods of controlling the material microstructure and its stability • to develop modeling techniques applicable for prediction of material behavior during the manufacturing process and service life-time • to increase material performance in the forecast application areas: particularly the intermetallics' ductility, toughness and resistance at room or high temperature, creep resistance, as well as biocompatibility in the case of SMA • to improve the processing routes for intermetallics allowing the transfer of novel technologies from laboratories to industry and their increase applications in structural elements • to reduce costs of processing route to make use of intermetallics more competitive with respect to state-of-art materials • to develop reliable techniques for production of mixed material elements where intermetallic thin films and layers serve as oxidation and erosion protective coatings	2010-2013

Elements to be included in the call	State of the Art	Vision / targets	Forecast
Metal Ceramic Composites Key action 1: Low-cost production processes. Key action 2: Multiscale modeling. Key action 3: Low-cost production of large volumes of nanoparticles. Key action 4: Ceramic-metal interface characterization. Key action 5: Dispersion of nanoparticles in ceramics, metallic matrices and coatings. Key action 6: Derivation of microstructure-property correlations for specific targeted properties, mechanical strength, elasticity, thermal and electrical conductivity. Key action 7: Joining of metal ceramic composites and integration with current materials in functional systems and devices. Key action 8: Development of advanced metal ceramic composite coating systems (e.g. porcelain/vitreous enamel coatings), multilayered materials and nanostructures to confer new properties on a material surface without affecting bulk properties. Key action 9: Metal ceramic composites with ceramic matrices with improved fracture toughness. Key action 10: Modeling for life time prediction - through life cycle. Key action 11: Carbon nanotube based metal ceramic composites, processing methods for new structures based on CNT integrated in ceramic and light weight metallic matrices for functional and biomedical applications. Key action 12: Functional metal ceramic composites for fuel cell applications to increase the conversion efficiencies of fuel cells. Key action 13: Metal ceramic composites for fission and fusion reactor technologies. Key action 14: MMC from waste materials as recycling strategy for problematic wastes and sustainable development / rational use of resources. Key action 15: Metal ceramic composites s for advanced high pressure die casting and near net shape manufacturing.	**Metal Ceramic Composites** The continuous research and funding of projects related to these materials took place after the early 1980´s. 25 years later the actual use of MMC and CMC in industrial applications is much lower than foreseen in the 1970s. In 1990 the worldwide market of MMC was estimated to be between 3-37 million US $ and in 1999 it was estimated to be around 103 million US $. 62% of this volume is within the ground transportation applications and 26.5% in thermal management applications. Aerospace comprises around 5.4% of the total market. Even though the too high final cost of the materials remain the most important reason that explains the current situation, there are other aspects that have also hindered the use of metal-ceramic composites such as difficulties in secondary processes, low ductility and toughness, anisotropy, lack of data regarding the behavior at long term, lack of data for modeling and simulation, lack of standardization. There is hardly any knowledge on long-term mechanical behavior and fatigue of the metal ceramic composites and relatively poor understanding and knowledge on interfaces in these materials. The production of nano-size MMC using SHS, plasma and spray-drying is worth consideration having in mind their potential application as coating materials.	**Metal Ceramic Composites** Modeling and simulation: Development of fundamental microstructure-property correlations to predict mechanical and functional properties of novel metal ceramic composites. Influence of nanoparticles on mechanical and functional properties of ceramic and metallic matrices Fabrication: Development of highly purified starting materials which have a strong effect on the structure and composition of the interfaces and on the evolution of the microstructure. Cost/performance ratio of new (nanostructured) products to be optimized. Improved, cost-effective processing methods to be developed. Further understanding of the influence of process parameters on properties. Development of new coatings for fibers to improve wettability as well cost competitive matrix/reinforcements combinations The strategy is to develop the capability to design and produce metal ceramic composites having tailored functional and mechanical properties to be applied in components and systems using inexpensive manufacturing processes.	2010-2013

Elements to be included in the call	State of the Art	Vision / targets	Forecast
FGM and Functional Multilayers Key action 1: Development of lead-free piezoceramic materials for novel actuators. Key action 2: Development of next generation lead-free solders including SnZn, Bi-containing and composite solders; lead-free high-temperature solders. Key action 3: Development of suitable electrode materials and poling methods for the new materials. Key action 4: Development of high temperature piezoelectric materials to push the application limit to higher temperatures. Key action 5: Development of non-ceramic functional layers with acting and/or sensing capabilities (e.g. SMA or magnetostrictive materials). Key action 6: Development of poling methods and design for long-time reliability, both for use at high temperature as well as for use for many cycles is required. Key action 7: Modeling of novel actuator materials with respect to possible degradation mechanisms for long-term use. Key action 8: Modeling and testing of piezoelectric FGMs with respect to optimal material design before poling and/or the optimal poling conditions. Modeling and testing of electromechanical, damage and failure behavior of piezoelectric FGMs. Modeling of optimal structural design of piezoelectric FGMs with respect to their electromechanical properties. Key action 9: Development of new ceramic semiconductor materials and understanding of their band structure. Methods of cost-efficient production of novel semiconducting ceramics, particularly in the form of dispersed nanoparticulates. Key action 10: Suitable doping elements and doping techniques, leaving accessible defect states and mobile charge carriers are required. Key action 11: New electronic designs for printable electronics with robust and affordable technologies. New printing machinery for cost-efficient printing of RFID tags. Key action 12: Quantitative, theory-supported identification of nano/micro elementary components and their mechanical/chemical/physical interaction in biological tissues. Key action 13: Development of nano/micro-structured biomaterials through integrated closed-loop 'processing-characterization-modeling'.	**FGM and Functional Multilayers** Lead-containing multilayer actuators are available, but have to be outphased due to environmental regulations. Tens of thousand of jobs are endangered if new materials cannot be developed. Japan is currently leading in the development of lead-free piezoceramics. Currently, very few materials with insufficient properties are available for high temperature motion control. The current materials cannot be used with high efficiency above 200°C. Once motion control is available above this limit temperature, more technologies can be available as well. The field of printed electronics is about to develop with many competing technologies. Printed semiconducting polymers for many technologies, e.g. for large displays have conquered large market shares, providing large employment opportunities. It is expected, that the same will happen with printed electronics based on ceramics. Qualitative, statistics-based description of structure-function-property relationships Trial-and-error procedures for testing novel biomaterials	**FGM and Functional Multilayers** Modeling and simulation: Ab-initio modeling of polarization as a function of electric field for new piezoceramic materials. Finite element simulation for electromechanical performance of new actuator materials. Simulation of charge flow in new printed ceramic and hybrid technologies Fabrication: Pushing to frontiers of science the fabrication low-temperature multilayer, non-toxic piezoceramic for superior motion control for billions of cycles and large frequencies appears feasibly. The vision is to develop the capability to design also new semiconducting ceramics for the booming communications industry. Experimental tools: Micro/nano/picoindentation, ultrasonic/acoustic testing, X-ray based techniques, multiaxial mechanical testing, etc. Theoretical tools: Mathematics of homogenization, Poro-micromechanics, Molecular dynamics etc. Technologies: Solid-liquid phase separation, starch consolidation, electrophoretic deposition, slurry coating etc.	2010-2013