SMART
Specific Support Action

Materials for a Better Life

Better Life Workshop, October 2006

Imprint

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SMART stands for 'Foresight Action for Knowledge Based Multifunctional Materials Technology'. It is a Specific Support Action (SSA) of the European Commission within FP6. SMART started in April 2005 and will analyse, within 2 years, the most relevant research fields in materials science.

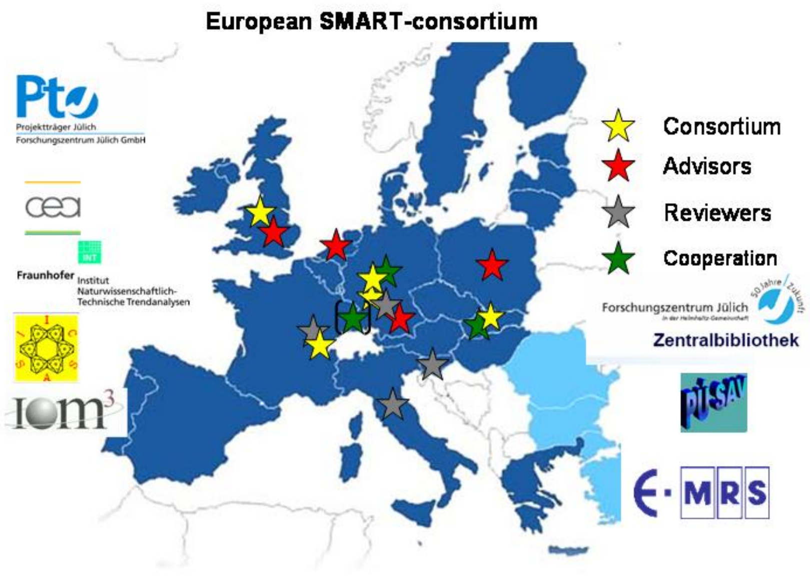
SMART objectives are:

- Improvement of European R&D-Position
- Improving public awareness especially of tax payers
- Enabling the further development of ERA.

These objectives are being achieved by:

- Identification of materials research hot spots for the future
- Mapping of European materials research activities
- Development of roadmaps
- Analysing foresight studies
- International benchmarking.

The following diagram shows the members of the SMART consortium.



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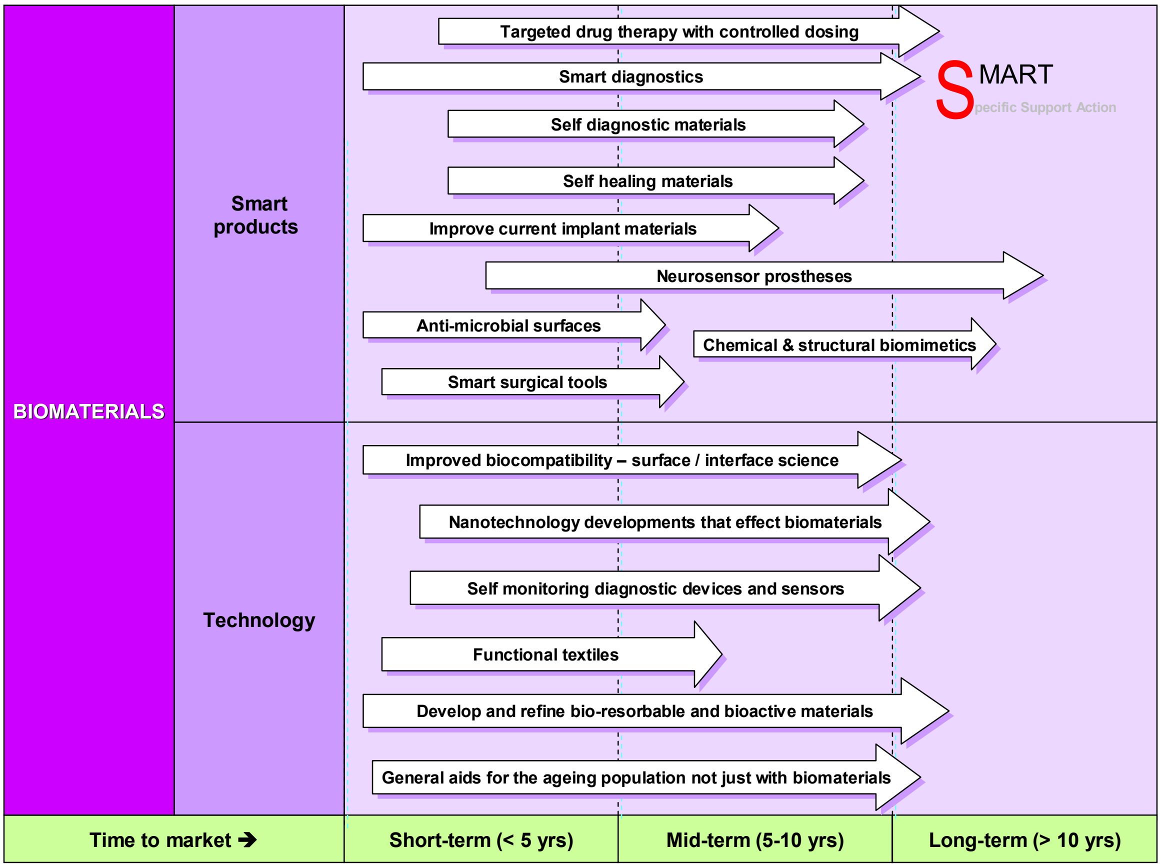
1.

EXECUTIVE SUMMARY

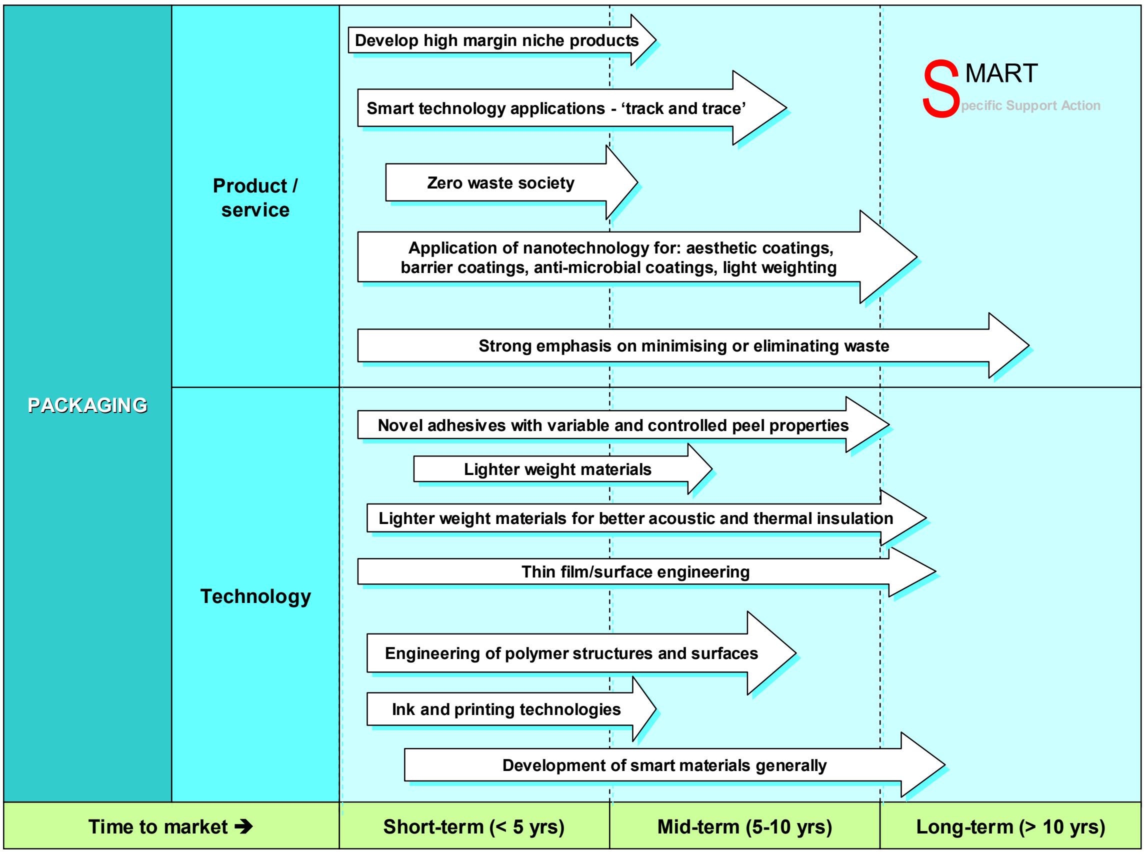
A Workshop was organised by the European SMART consortium, to have experts, in the fields of biomaterials, packaging and technical textiles, update a previously proposed roadmap for **Materials for a Better Life**.

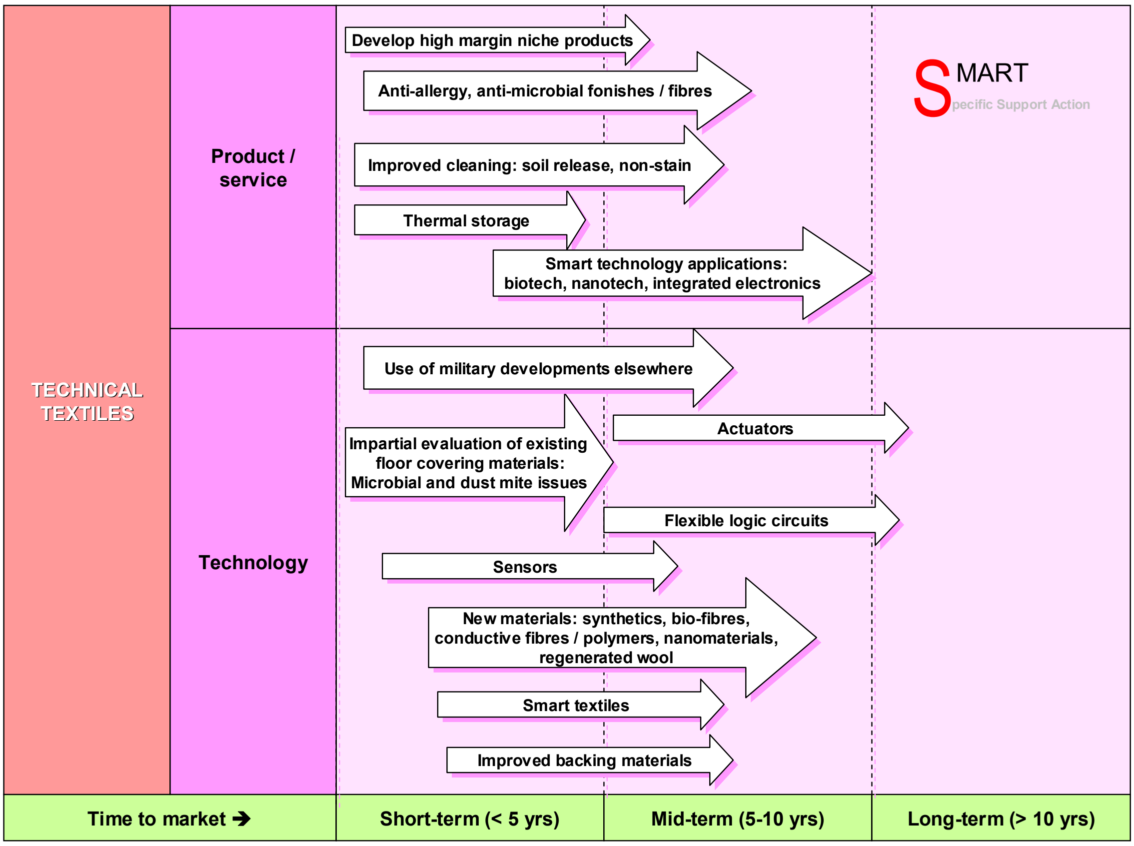
This was held in Lisbon on 22nd and 23rd October 2006, and Dr Martyn Chamberlain from the European Commission gave a welcoming address and presented the latest position regarding future funding for the next European Framework Programme (FP7).

The Workshop followed the process now commonly used for roadmapping. Three invited speakers gave presentations on the topics being considered, before the expert contributors provided their vision of the future, and what they saw standing in the way of progress for Europe. Once the barriers had been identified, proposals for future development effort were suggested. The roadmaps were updated to include the contributors' comments.



The importance of materials for the disabled and ageing population was highlighted and offers a lot of scope for future development activities.


PACKAGING
Product / service
Develop high margin niche products
Smart technology applications - 'track and trace'
Zero waste society
Application of nanotechnology for: aesthetic coatings, barrier coatings, anti-microbial coatings, light weighting
Strong emphasis on minimising or eliminating waste
Technology
Novel adhesives with variable and controlled peel properties
Lighter weight materials
Lighter weight materials for better acoustic and thermal insulation
Thin film/surface engineering
Engineering of polymer structures and surfaces
Ink and printing technologies
Development of smart materials generally
SMART
Specific Support Action
Time to market ➔
Short-term (< 5 yrs)
Mid-term (5-10 yrs)
Long-term (> 10 yrs)


TECHNICAL TEXTILES
Product / service
Develop high margin niche products
Anti-allergy, anti-microbial fonishes / fibres
Improved cleaning: soil release, non-stain
Thermal storage
Smart technology applications: biotech, nanotech, integrated electronics
Technology
Use of military developments elsewhere
Impartial evaluation of existing floor covering materials: Microbial and dust mite issues
Actuators
Flexible logic circuits
Sensors
New materials: synthetics, bio-fibres, conductive fibres / polymers, nanomaterials, regenerated wool
Smart textiles
Improved backing materials
SMART
Specific Support Action
Time to market ➔
Short-term (< 5 yrs)
Mid-term (5-10 yrs)
Long-term (> 10 yrs)

2.

CONTRIBUTORS

The following people attended a meeting in Lisbon, Portugal on 22nd and 23rd October 2006 to formulate a roadmap in Materials for a Better Life:

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3.

METHODOLOGY

The methodology used for this roadmap is summarised in Appendix 8.1, following the procedures typically used for other roadmaps that have been produced.

Experts are asked to provide their thoughts and opinions for the four main stages of the roadmapping process:

- Where are we now?
- Where do we want to be?
- What is stopping us getting there?
- What needs to be done to overcome the barriers?

For each stage, large hexagon *Post-its* are used to gather each input. These are then clustered under common topics as a spokesman from each group presents their findings. This draws comments from the rest of the participants and generally arrives at a consensus of opinion.

Using adhesive stickers, priorities are given to what are considered the most important issues for the second stage of the roadmapping process, enabling a key priority list to be established for subsequent steps.

The final outcome is a list of priority items that need action in order to enable the industry to progress in a more dynamic and competitive manner.

As with other roadmaps, once this first edition is produced, comments are sought from others in the field, so that ownership comes from the entire community.

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4.

CURRENT SITUATION

The SMART consortium had previously produced a draft roadmap for Materials for a Better Life, and the meeting Lisbon was called to refine that roadmap.

The first phase of a roadmapping process is to consider ‘Where are we now?’.

A number of recent publications had been found that were relevant to the future trends in materials for security. By way of introduction, these are summarised in Appendix 8.2.

Presentations on current advances in the sector were given by the following:

Dr Christian Oehr, Fraunhofer IGB, Stuttgart – *Tailor-made Materials for Interaction with Biological Systems*

The global consumption of plastics in medical technology is dominated by PVC, with polyethylene, polypropylene and polystyrene being next in order. Technical plastics such as polyesters, ABS and SAN, polycarbonate and TPE are used in much smaller quantities. Annual growth in medical plastics is 8% in Europe and the US, but is 15% in China.

Polymers with improved optical, chemical and mechanical properties are being developed. COC (e.g. Topas from Ticona) have excellent optical properties, with high glass transition temperature. Cyrolite (MMA, butadiene, styrene) is a more solvent resistant acrylate. PEX-PF, a polyolefine based, PVC substitute is fivefold more expensive than PVC so is only in use for small tubes. PEEK has started to replace titanium for some applications.

Christian Oehr defined biocompatibility as “the ability of a biomaterial to induce the appropriate answer in a specific application”, and went on to add that the requirements of volume properties of polymeric materials is that they have to be chemically and mechanically stable in a biological surrounding; should not be allowed to release remaining monomers, additives, or auxiliary materials; must withstand sterilization procedures; and in some cases (e.g. diagnostics) should have excellent optical properties.

The US healthcare market in 1998 was worth in excess of $1 trillion for IOLs, hip and knee prostheses, vascular grafts, heart valves, percutaneous devices, stimulatory electrodes, catheters,and stents. All of these applications could benefit from improvement in the materials component or their biocompatibility. Coating techniques for better biocompatibility are used to improve the length of time products last, and these are plasma, corona, irradiation, texturing, dip coating, Parylene use, ozonisation, silanisation, spray coating, sputter coating, and photo coupling.

For micron films, the properties are dependent on thickness and provide protective coatings, coatings with specific transport properties, and defined release coatings. For nanofilms, the properties are not thickness dependent, and provide tailored surface energy (wettability or water repellancy); enhanced adhesion between polymers and metals; interaction with biological systems; separation membranes and ion-exchange materials.

Polymeric systems are replacing glass in medicine and pharmacy, as seen with contact lenses, membrane modules, and catheters.

Dr Paul Butler, Packaging Innovations – *Packaging for a Better Life*

Packaging has many problems: too many identical products, labels that cannot be read or understood and packages that cannot be opened. There is a demand for more information, and there are expectations of support for on-the-go lifestyles. The demands on packaging are for improvements in convenience, safety and error prevention, improved product performance, and easier openability / readability. There are a number of societal drivers: family changes, ageing demographics, support for healthy and safe lifestyles, design for the environment, and sustainability with easier recycling.

Between 1977 and 2021 there will be a 30% increase in over-65s, who will be more active than in the past and as they age packaging will need to adapt to cater for their needs.

Things are beginning to change with soups that heat up and drinks that cool down, and there are attempts to enable easier opening of packaged items.

Anti-counterfeiting, and error prevention with ‘track and trace’ is being addressed. The market is seeing monitors on the packaging to monitor food quality, and electronic use-by dates. The aim is for better self-adjusting use-by dates. Nature does it best with some products; bananas are an excellent example where the skin changes colour as the fruit ripens. Readiness-to-eat colour coding has been developed for packaging some fruit, with a crisp/firm/juicy indicator.

Dr Butler showed examples of how some products have been designed for unique and safer dispensing: ‘Duck’ products for squirting on the inaccessible parts of toilets; bottles that pour out two liquids at once (cream liqueurs); ketchup bottles that stand upside down.

The design of materials is crucial to future developments in packaging, and the consumer has the real insight into the problems that affect the quality of their lives.

Professor Subhash Anand, University of Bolton – *Technical Textiles Enhance the Quality of Life*

These talks provided an excellent background on the current state of applications for Materials for a Better Life.

5.

FUTURE DIRECTION

For the second stage of the roadmapping procedure, “Where do we want to be?”, the technique was to ask those present to split into groups and brainstorm their vision of what would happen in the future in this sector.

To stimulate further thought, the following questions were posed:

- What is our vision for the future?
- What should we be doing to maximise benefit for Europe?
- Are we doing something now that we should put more effort into?
- Are we doing something currently that we should drop?
- What is going to make a real impact on our activities?
- What new areas should we be working in?
- Are there opportunities for creating spin-out companies?

The ideas from the participants are shown in Appendix 8.3, and are reproduced in the following diagram (Figure 1), with dots (●) indicating the level of priority judged by the team. The ranking is shown in red.

Figure 1: Future Direction (● indicates priority level)	
NATURAL MATERIALS	~ Biomimetic structural design ●●●●●●●●●●●●● (1) ~ Anti-microbial packaging using natural biocides ●● ~ Body healing materials should include naturally occurring materials
MATERIALS TECHNOLOGY	~ Self healing structures ●●●●●●●●●●●● (2) ~ Better drug control release through self regulation ●●●●●● (6) ~ Use of lighter weight materials for acoustic and thermal insulation especially to reduce noise pollution ●●●●●● (7) ~ Impact of nanomaterials ●●●● ~ Self-assembling polymer ●● ~ Interacting hydrid materials ●● ~ Smart materials such as piezoelectrics and thermochromics ●● ~ Electro-spinning processes ● ~ Promotion of integration of technologies
IMPLANTS	~ Tailoring and improvement of traditional implant engineering materials in the medium term ●●●●●●●●● (4) ~ Artificial organs and tissue in the long term ●●●●
DISABILITY	~ Distinct needs of young disabled people, as well as the ageing population ●●● ~ Multi-purpose equipment for living cells ●
SUSTAINABILITY	~ Sustainability issues need addressing in all areas of materials for a better life ●●●● ~ Hydrid materials should be recyclable
SURFACES	~ Improved tooth replacement techniques ●● ~ Bioactive surfaces supermarket ●● ~ Single stage processing for internal and external ●● ~ Development of high resolution surface techniques ● ~ Reactive surfaces - catalysis
HEALTH	~ Long life with quality ●●● ~ Personalised medicine with targeted drug delivery ●● ~ Recognising surface in medicine ●
SOCIETAL ISSUES	~ Zero waste society ●●●●●●●●●● (3) ~ Need effective mass produced smart products, not just high value niche products ●●●●● (8)

SENSORS	~ Self monitoring diagnostic devices and sensors ●●●●●●● **(5)** ~ Intelligent homes ●●●●● **(10)** ~ Specific self-diagnostic sensors that are easy to use ●●● ~ Biocompatible sensors ●● ~ Intelligent sensors ● ~ Use of 'satellite' mobile phones as scanners to provide information on cost of material ● ~ Neuro-sensor exoskeleton ~ Dog detecting cancers – sensors ~ Remote information about packaging sent down to a mobile phone
ENVIRONMENT	~ Materials with adaptive chemical properties – adapting to the environment ●●●●●● **(9)** ~ Desalination technology for water ●●●● ~ Technology for zero acoustic emissions of trains and vehicles ●●● ~ Water conservation through use of polymers, gels, membranes, etc. ● ~ Culture of recyclability ~ Should we rely on old materials or on old materials in new combinations (conjugate / hybrid)
ENERGY	~ Petrol free aircraft ● ~ Low energy production of raw materials and low temperature production of composite materials ● ~ Energy efficient aviation
TEXTILES	~ Controlled tunable clothing ●●●● ~ Smart article of clothing to be used to protect against cold, heat, etc. ●●● ~ Therapeutic clothing e.g. drug delivery enhancement ● ~ Lower cost functionable clothing ~ Materials to indicate emotions – emotional communication
ANTI-MICROBIALS	~ Improved non-silver antimicrobial agents ● ~ Better self-disinfecting properties
GENERAL	~ Interdisciplinary research ●●●●●
PACKAGING	~ Pesticide detector ●●● ~ Label communicating in language to indicate content to purchaser ●● ~ Easy opening hard to tamper packaging ● ~ Food traceability
BIOCOMPATIBILITY	~ Drug / gene / DNA / stem cells delivery for repair ●●● ~ Improved target selectivity ~ Rejection avoidance ~ Surface / body interactions

The main priorities raised are shown in the following diagram:

Main priorities for future direction in Materials for a Better Life	
NATURAL MATERIALS	Biomimetic structural design **(1)**
MATERIALS TECHNOLOGY	Self healing structures **(2)** Better drug control release through self regulation **(6)** Use of lighter weight materials for acoustic and thermal insulation especially

	to reduce noise pollution **(7)**
IMPLANTS	Tailoring and improvement of traditional implant engineering materials in the medium term **(4)**
SOCIETAL ISSUES	Zero waste society **(3)** Need effective mass produced smart products, not just high value niche products **(8)**
SENSORS	Self monitoring diagnostic devices and sensors **(5)** Intelligent homes **(10)**
ENVIRONMENT	Materials with adaptive chemical properties – adapting to the environment **(9)**

These top priorities were discussed by the groups during the next phase of the roadmapping procedure: looking at the barriers to achieving the vision and what needs to be done to overcome those barriers.

6.

BARRIERS TO PROGRESS AND POSSIBLE SOLUTIONS

Having arrived at a consensus of the future direction for Materials for a Better Life, the next stage was to determine *"What is stopping us getting there?"* and deciding *"What needs to be done to overcome the barriers?"*. For this stage yellow Post-it hexagons were used to identify the barriers.

Typical questions asked were:

- Do we have the skilled people we need?
- What are the gaps in our technology?
- Is funding likely to be adequate?
- Do we have the necessary infrastructure?
- What is inhibiting manufacture?
- Are patents inhibiting progress?

Actions needed to overcome the barriers (shown in blue) are also included in the following table (Figure 2), and are taken from the hexagons shown in Appendix 8.4. The priorities are those indicated by participants in the Workshop.

Figure 2: Barriers and Possible Solutions

NATURAL MATERIALS

(1) Biomimetic structural design

Barriers	Solutions
We do not understand fully the mechanisms of natural materials, and their assembly techniques. Nature is very complex and there are discrepancies between in vivo and in vitro.	Need more interdisciplinary research to understand the problems – an infrastructure should be crerated to allow this to happen. EU needs a virtual network in biomimetics.

MATERIALS TECHNOLOGY

(2) Self-healing structures

Barriers	Solutions
We do not know the mechanism for making certain self-healing structures. There is a lack of understanding about the interactions and the complexity. There is a lack of infrastructure of in vivo experimental work.	Need to distinguish between biomaterial (organic) stem cell strategy and inorganic materials such as shape memory alloys. Living polymers that are dormant but become active on an external stimulus. More modelling required.

SOCIETAL ISSUES

(3) Zero waste society

Barriers	Solutions
Zero waste not consistent with thermodynamic principles of physics. There has to be a real desire to do it. There is a lack of information about possibilities. It is often more difficult than just throwing away. Design a product with zero waste in mind. Behaviour. Wider social issues.	Biodegradable materials. New surfaces for longer life, with better cleaning for new interfaces. Better to use recyclable materials – someone's waste is someone else's starting material. Eat local produce! Local disposal in the home should be a goal. Minimise usage in the first place. There has to be appreciation of immediate benefits and consequences. Include psychologists and sociologists.

(8) Need effective mass produced smart products, not just high value niche products

Barriers	Solutions
Smart materials are not sustainable (tend to not have a long lifetime). Mass produced smart materials are not usually cost efficient.	Better surface regulation. Structural design has to allow deformation.

IMPLANTS

(4) Tailoring and improvement of traditional implant engineering materials in the medium term

Barriers	Solutions
Temporary or permanent implants need to prevent reaction with the body. The implant material should be replaced in time by natural body material.	For temporary implants, bio-absorbable materials should be used. For permanent implants, decision is to use cheaper throw away implants or more expensive more reliable longer lasting implants. Degradable material should be replaced by own material.

SENSORS

(5) Self monitoring diagnostic devices and sensors

Barriers	Solutions
An ethical issue is – do we really want this? Sensors are invasive and should be miniaturised.	Develop non-invasive less intrusive techniques. Nanotechnology developments should provide

Sensors for DNA are often inaccurate and not sensitive.	solutions. Develop accurate, portable DNA sensors

MATERIALS TECHNOLOGY

(6) Better drug control release through self regulation

Barriers	Solutions
It is hard to standardise for different patients, since each individual is unique. There is a lack of uniformity of drug control release. External wounds need to be kept moist. Targeting specific cells to correct site and releasing the correct amount. For self-healing structures, the loop until the damage or defect is correctly healed or cured is detection→measurement→healing control.	For drug control we need sensors, electronics, adaptive polymers.

(7) Use of lighter weight materials for acoustic and thermal insulation especially to reduce noise pollution

Barriers	Solutions
Lightweight materials tend to be fragile, expensive, sensitive to water and the environment. For acoustics, smart materials are too complicated and too expensive.	Surfaces should be made more hydrophobic, and an organic component could be used to make material more ductile. Improve energy efficiency.

ENVIRONMENT

(9)
Materials with adaptive chemical properties – adapting to the environment

Barriers	Solutions
There is a lack of focus on textiles.	Learn from what is happening in military applications.

MISCELLANEOUS – the following additions were made to the priority list

Over reliance on modern technology

Barriers	Solutions
Low level of basic research on protein interaction.	More interdisciplinary research. Better mapping of knowledge. Modelling of realistic systems.

Disability

Barriers	Solutions
There is technology already being developed which could help people with disabilities but it is not being turned into practical applications, and/or they are not being given to the people who need them.	Communication between the supply chain and the provider needs to be improved. There needs to be more communication between researchers and the disabled community – we need knowledge transfer to the industry.

Funding

Barriers	Solutions
There is a gap in funding between principle and exploitation. Lack of service staff for technical equipment.	Better selection of promising work for further funding. Life time funding should be adopted. There needs to be a database of available equipment. Funding should support full cost.

Education

Barriers	Solutions
Patient awareness. Skills connecting expertise. Lack of collaborative research.	Make effort to improve awareness. Funding for short term mobility with no age restrictions. Promote more collaboration.

7.

ACTIONS / RECOMMENDATIONS

Materials for a Better Life is particularly broad, and the Workshop identified gaps in the previous roadmaps produced for the sectors identified as important:

- Biomaterials
- Packaging
- Technical textiles.

During the workshop other areas such as materials for the disabled and ageing were identified as particularly important.

The main issues are summarised below and have helped add or emphasise features for the updated roadmaps.

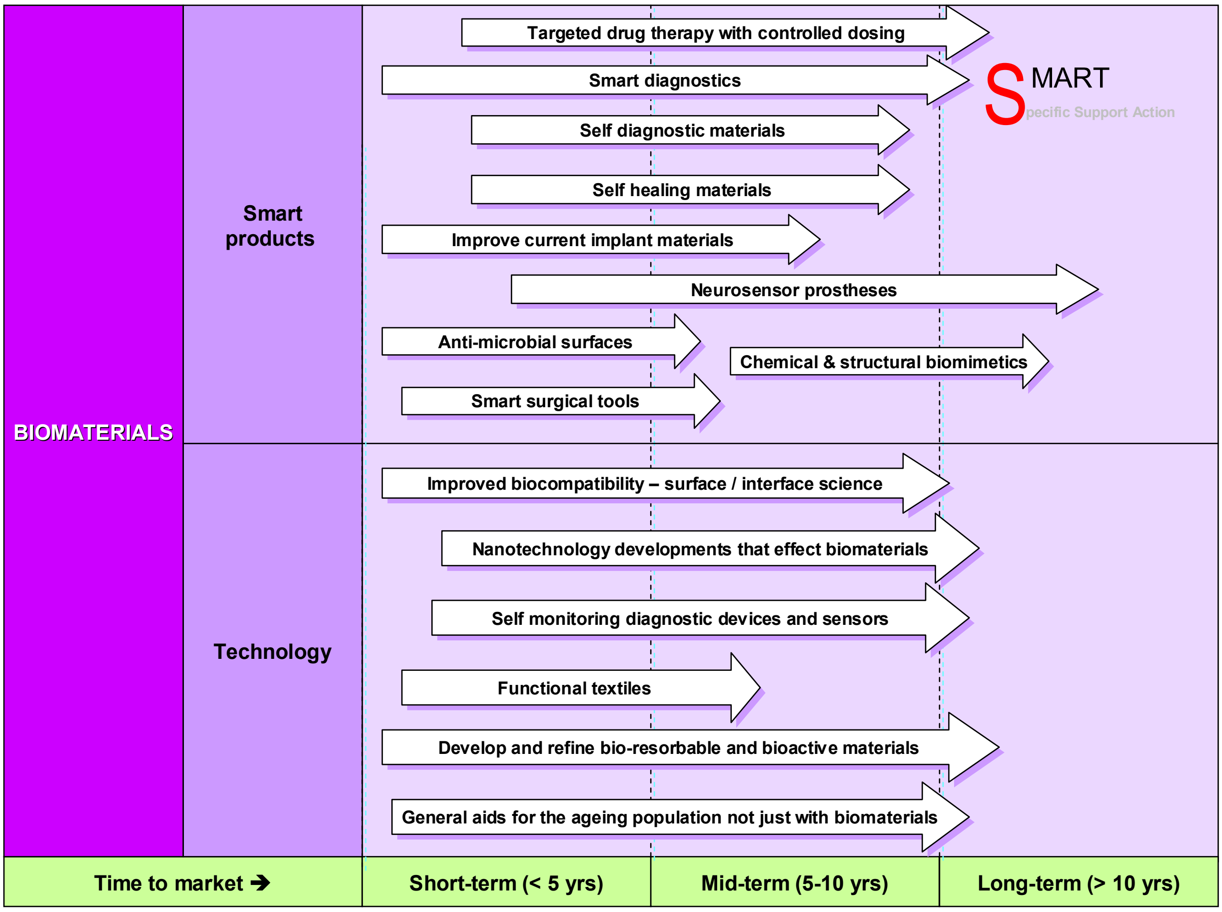
Biomaterials

Points raised by the Workshop participants:

- Strong emphasis needs to be placed on biomimetic structural design (evolution has provided the best solutions so far), but there is a lack of understanding of the complexity. It is suggested that a network in biomimetics for Europe could provide information and focus on what is especially multidisciplinary research.
- Self-healing structures (not just for biomaterials) is an embryonic field of research which could provide advanced solutions for many areas of healthcare.
- There needs to be improvements made in biocompatibility of implants between the component and the body, in order to reduce rejection or infection.
- More effort is required to provide better drug control release through more self regulation.
- Diagnostic sensors that are self-monitoring should be designed to be non-invasive and non-intrusive. Nanotechnology developments are likely to provide opportunities.

Although disability aspects of materials development have been recorded in this section, it is recognised that there is a great deal of scope for development of other materials, not just biomaterials, to help the disabled and the ageing population. Better communication between all parties involved would help provide focus for future developments.

The updated roadmap is produced below:

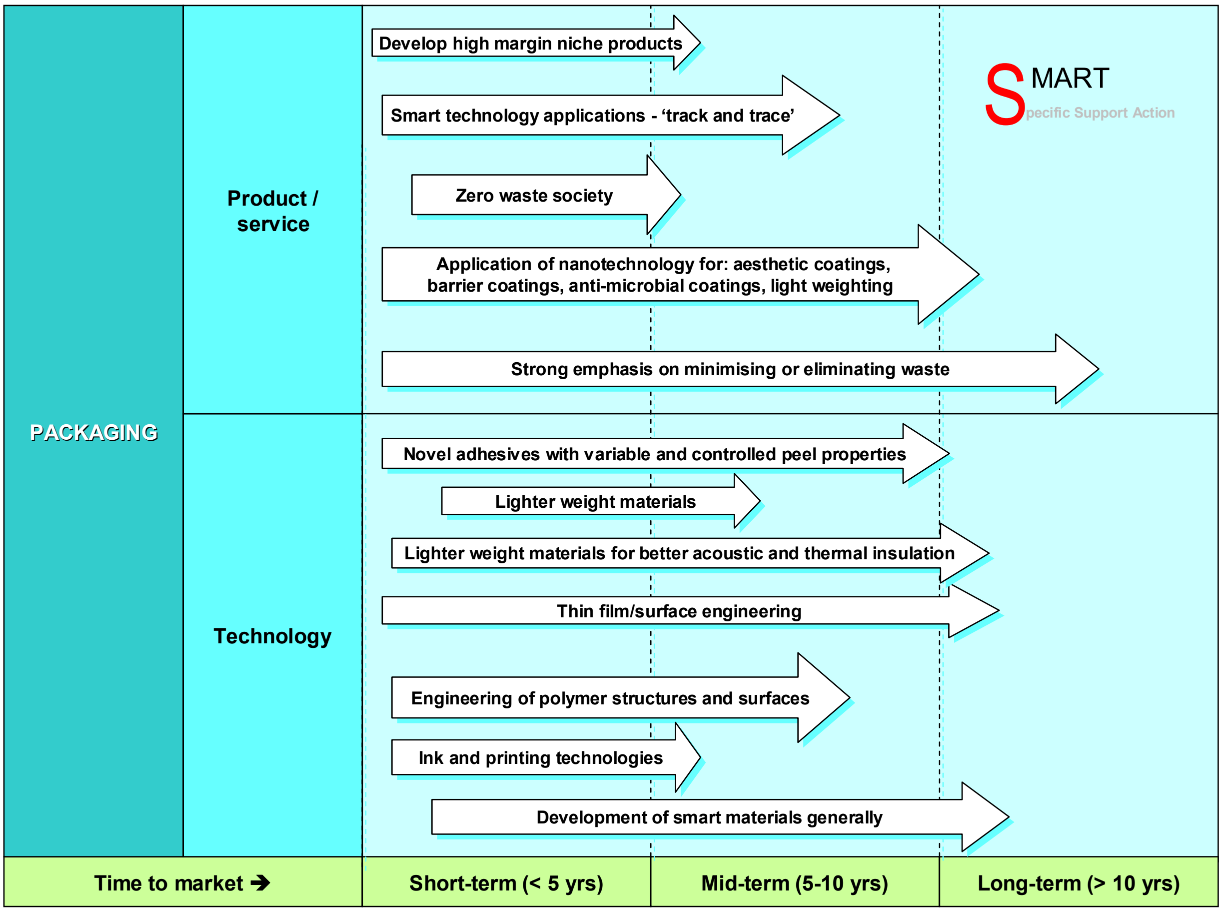


Packaging

A number of points were made about the development of materials for packaging:

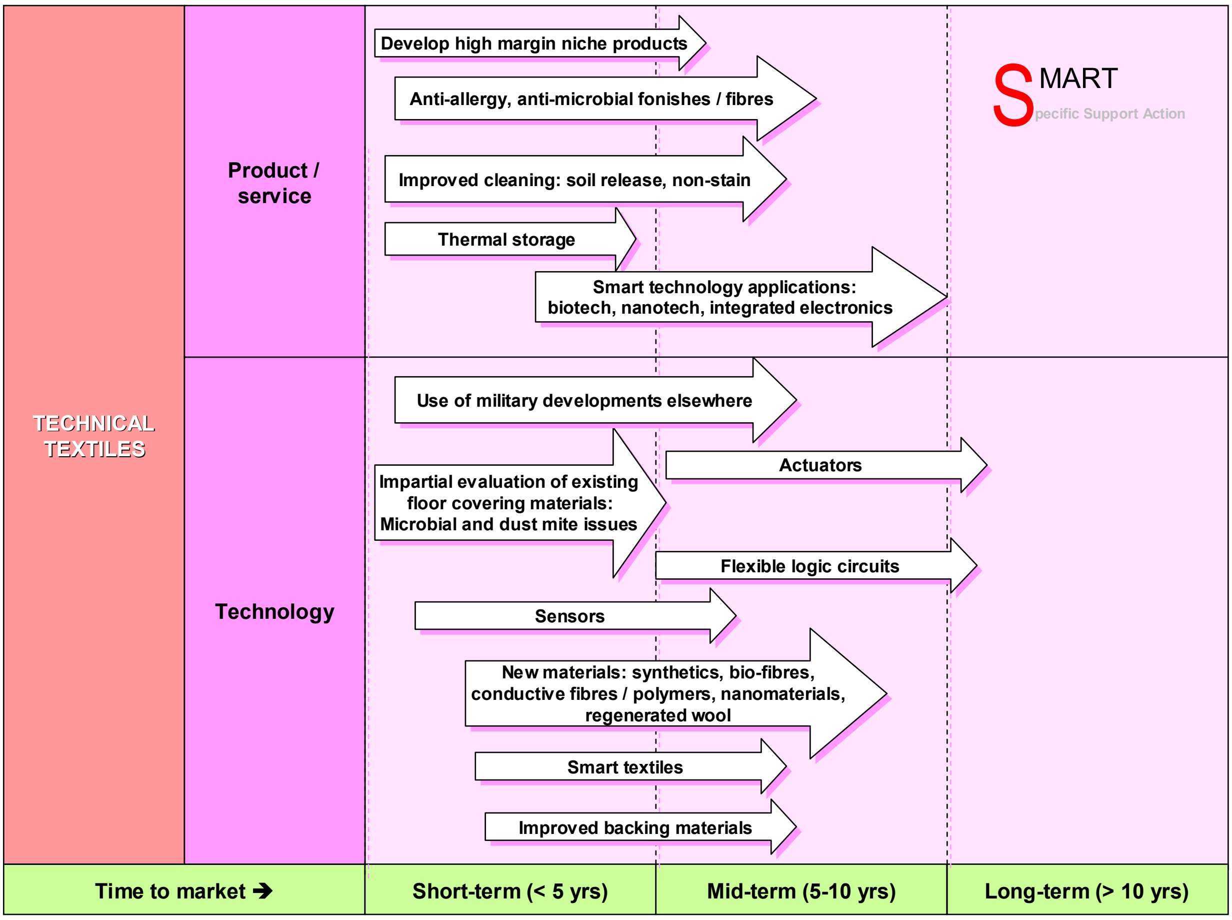
- Minimise usage in the first instance, designing to achieve zero waste.
- Aim for zero waste by having more efficient recycling.
- There has to be a real desire or incentive to minimise waste.
- Use of sensors more for 'track and trace', and for detection of spoilage or contamination. There is some potential here for mass produced smart materials.
- Look closely at nanotechnology which has the potential to provide barrier properties and lightweight materials.

The roadmap has been updated:



Technical Textiles

The main point which has now been included in the updated roadmap is that there is a lot to be learned from developments in technical textiles for military applications.



Miscellaneous

The following general points were made:

- There is too often a funding gap between taking good research to production. There should be better selection of promising work for further funding.
- There should be an inventory of what equipment is available for use.
- More collaborative work is required.

This Workshop is not the final phase of the roadmap. The views of the wider community will be sought, and as with other roadmaps the report should be re-visited annually to discuss changes and progress.

8.

APPENDICES

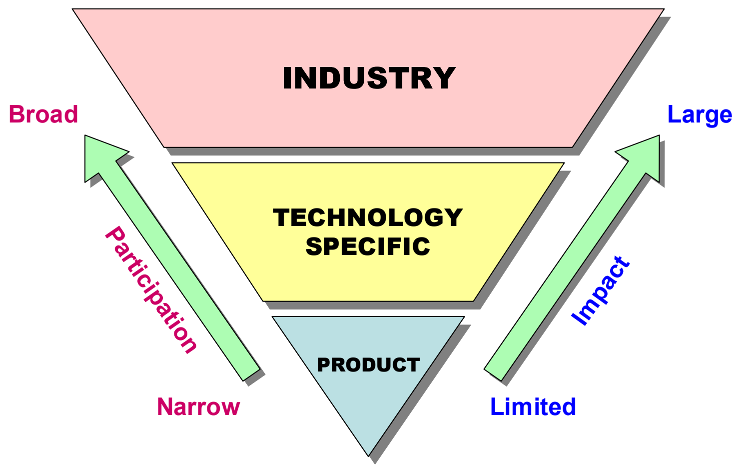
8.1 Methodology for Roadmapping

What is Roadmapping?

Based on a Foresight model, roadmapping is a high-level planning tool to help both project management and strategic planning in any technically-based establishment, whether in academia or industry.

Motorola first coined the word roadmapping in the seventies, but only recently has it been widely adopted by both individual companies and industry sectors as an essential part of their future growth. Figure (i) summarises the types of roadmaps that have already been produced. They can be for industries such as "glass" and "petroleum", or for specific technologies such as nanomaterials, biocatalysis, etc. Some roadmaps have been produced just for single product areas.

Figure (i): Types of roadmaps

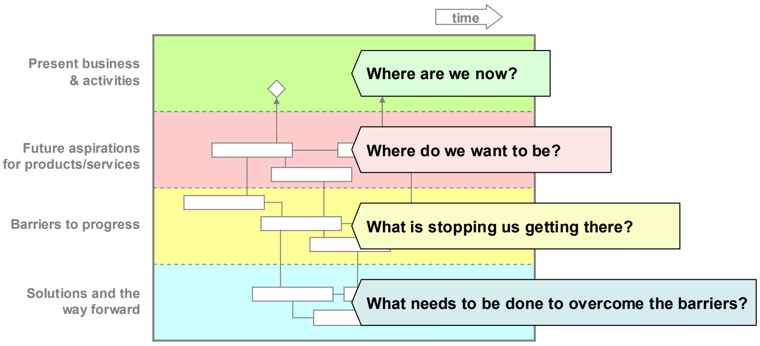


How are the Roadmaps produced?

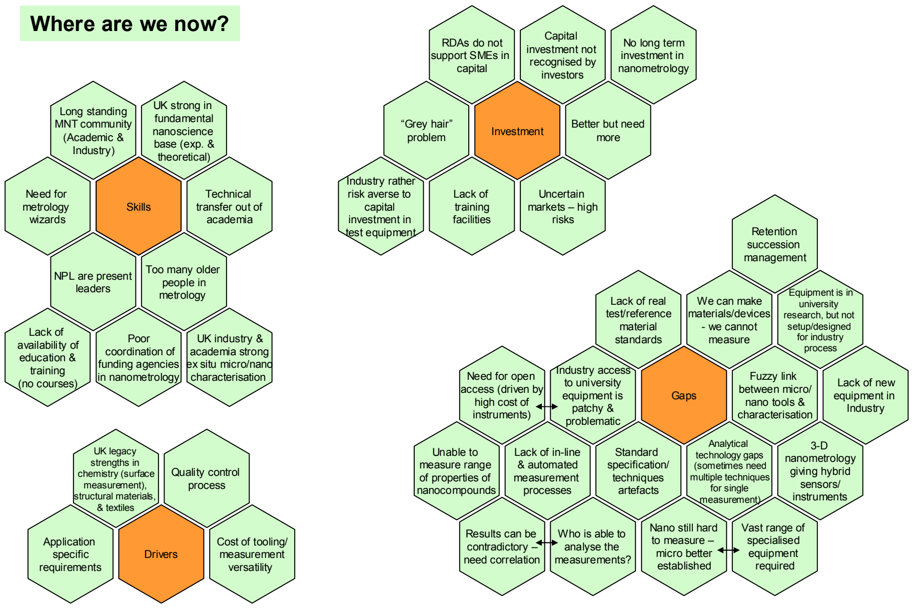
The process gathers together groups of commercial as well as technical experts, and takes them through the four stages that are shown in Figure (ii). The participants need to have sufficient information about the markets and the business to say where the topic under consideration is at the present time. The first step is to agree what the present situation is, and then to move on to provide a vision of where they see things going in the future - where they want to be during the next 20 years.

The third stage is to determine what the barriers to achieving the objectives and goals are. Finally decisions and proposals need to be made to enable the barriers to be overcome. These are arranged over a timescale, with short-term (0 to 3 years), medium-term (3 to 10 years), and long-term (> 10 years) goals.

Figure (ii): Stages in the Roadmapping exercise



Hexagon shaped *Post-its* (colour coded for each stage) are used to gather the participants' thoughts for each step. These are then grouped into topics, and a typical example is shown in Figure (iii). When a consensus is reached regarding the conclusions, "dot" stickers are added to indicate the main priority items.



Such roadmaps provide a collective opinion about the future strategy, with agreed objectives.

As soon as the roadmap has been completed, it can be sent out to other interested parties for their additions and comments.

Roadmaps are "live" documents and should be updated on a regular basis.

8.2 Background Information on Materials for a Better Life

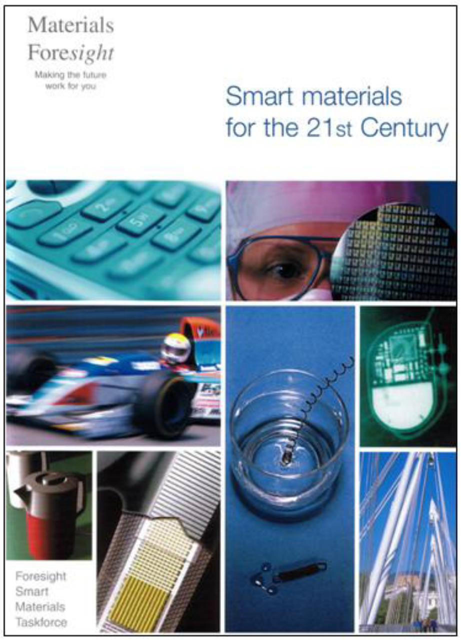
There are a number of roadmaps, foresight exercises and strategy documents that refer to the use of new materials for a better life.

The following summaries highlight the main ones. They are sectioned into ones that are quite general and those that are specifically related to either biomaterials, packaging or textiles.

MISCELLANEOUS

MATERIALS FORESIGHT – SMART MATERIALS FOR THE 21ST CENTURY

In 2003 the Materials Panel for the UK Government's Foresight exercise produced a booklet entitled *Smart Materials for the 21st Century* (http://www.iom3.org/foresight/Smart%20materials%20web.pdf), which adopted a market-oriented approach encompassing:



- Transport
- Agriculture, food and consumer packaging
- Construction
- Sports and leisure
- White goods and domestic products
- Healthcare.

In the executive summary, it makes it clear that a technology-driven review was not the aim, since there is considerable literature already on classes of materials such as piezoelectrics, photochromics, electro-rheological fluids and shape memory alloys. It comments that there is no shortage of potential technical solutions in this area but, equally, no single solution will fit all applications. The need is, rather, to enhance the practical realisation of the existing materials-based technologies, tailored to particular customer and market requirements.

The expert task force recommended that initial emphasis should be placed within three sectors:

- **Food and packaging**
  The requirement is to develop materials technology that provide pragmatic and cost-effective solutions to smart labelling and packaging. Europe already has expertise in this area, and is well placed to exploit smart materials technology in the implementation of traceability protocols to improve food quality and safety.

- **Healthcare**
  The targeted development of smart biomedical materials and systems technology within this sector will consolidate the UK's world-class status in biomaterials, implants, external prostheses and tissue engineering-related areas. Key to this activity is an understanding of the bio-interactive behaviour of materials and the development of bio-compatible components and devices.

- **Automotive / motorsport**
  The UK has a strong position in motorsport and the introduction of smart materials will consolidate that standing in the face of increasing competition. Developments in this area eventually flow down into the mainstream automotive sector.

The report provides an excellent view of what is needed for the future.

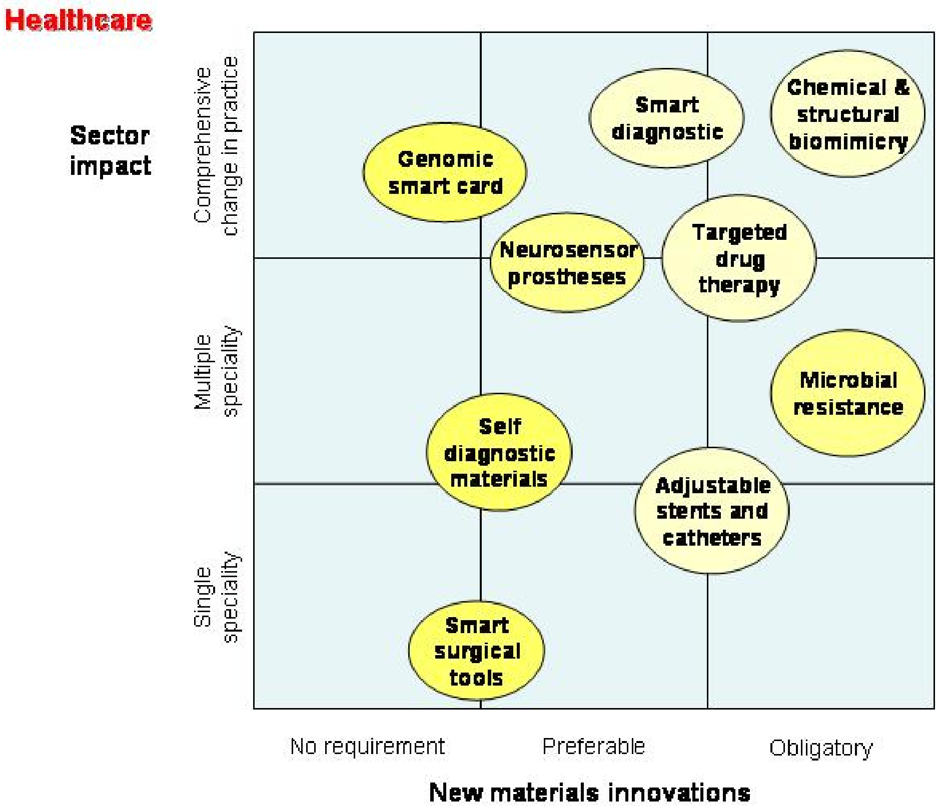
Many of these applications are being addressed by smart materials, and barriers to exploitation of smart materials in this sector are given as:

- Better materials properties
- System compatibility (materials available in suitable form for application)
- Availability and cost
- Better awareness and acceptability of smart materials in traditional engineering sectors
- Spin-off from other sectors needs to be achieved.

Generally the smart materials supply opportunities lie with new:

- Speciality polymers
- Coatings
- Adhesives
- Composites
- Inorganic materials
- Metals
- Biotechnology and biomaterials.

In the healthcare sector the opportunities were identified as shown in the following diagram, with the comment that incentives could be enhanced considerably with smart materials, if set as a priority for cross-disciplinary funding.



A EUROPEAN TECHNOLOGY PLATFORM FOR SUSTAINABLE CHEMISTRY – MATERIALS TECHNOLOGY – SUSCHEM

SusChem, the European Technology Platform for Sustainable Chemistry has produced (2005) a strategic research agenda, in draft form (http://www.suschem.org/media.php?mId=2678). Development priorities are listed as:

- Fundamental understanding of structure property relationships
- Computational materials science
- Development of analytical techniques
- From laboratory synthesis to large scale manufacturing.

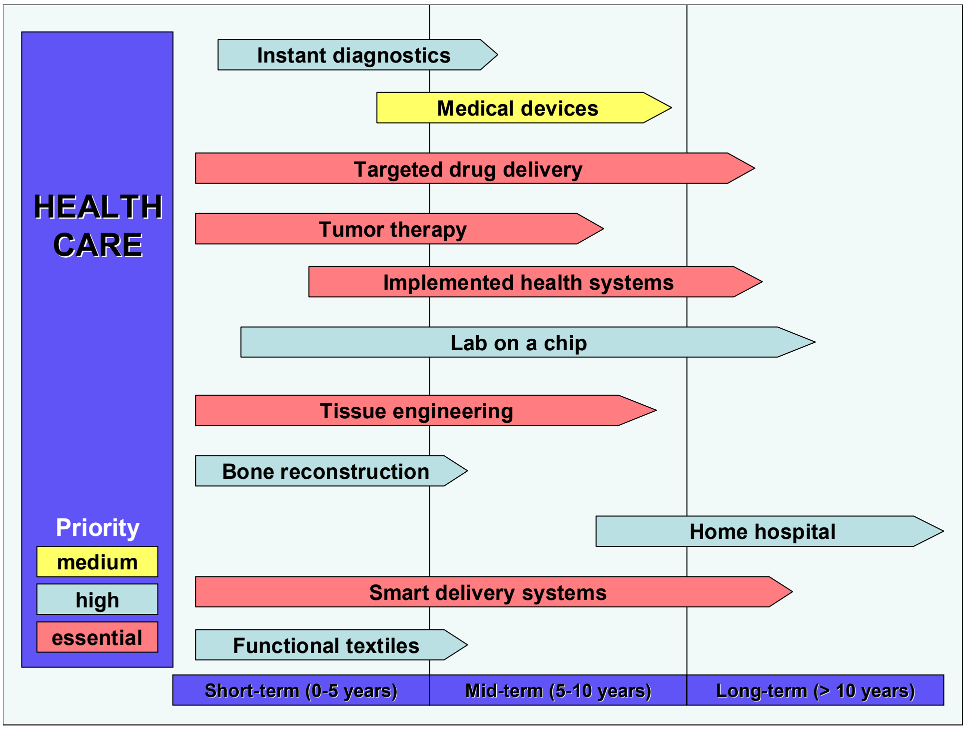
There is strong emphasis on nanotechnology, and the report focuses on producing roadmaps for the following areas:

- Materials for energy management
- Materials for the electronics industry – communications, information, entertainment
- Materials for medicine, agriculture, nutrition – healthcare
- Materials for the enhancement of quality of life
- Materials for citizen protection
- Materials for transport and mobility.

For each of these fields, small roadmaps are produced with priorities on a scale of medium → high → essential, and the projects are described as short-term, medium-term and long-term.

'Smart' is used on a number of occasions in the healthcare, and quality of life text. For those two sections, the roadmaps and key points and produced are summarised below:

Healthcare:



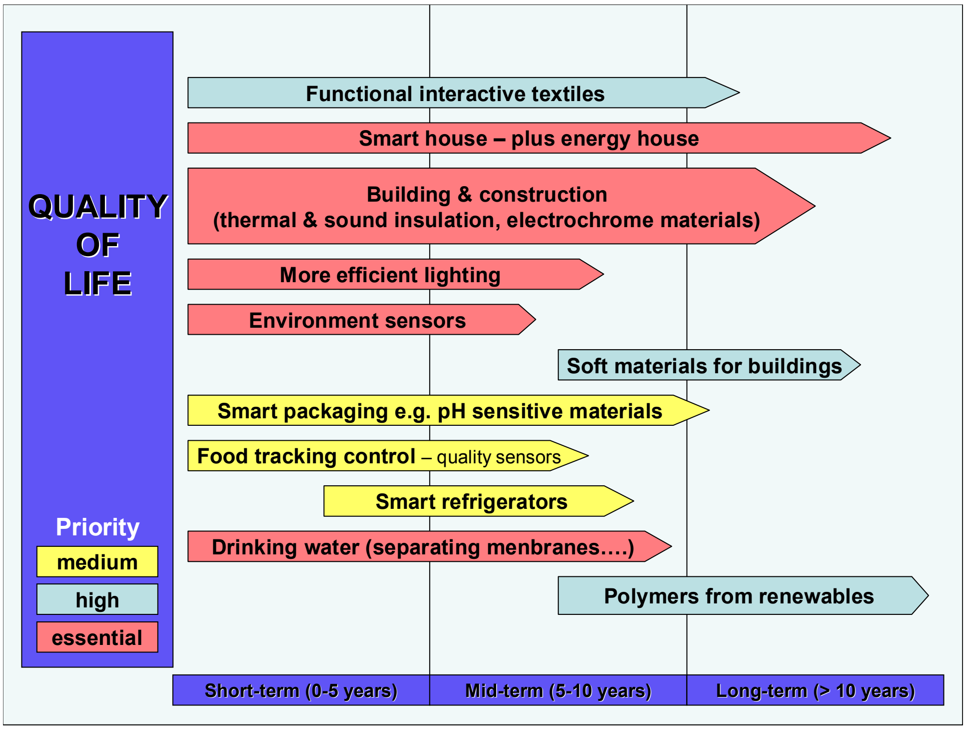
The driver is increased life expectancy and the requirements are:

- Optimal and personalised medical care
- High demand for health prevention to reduce increasing medical costs
- New materials for
    - *Implants*
    - *Drug delivery*
    - *Novel therapeutics*
    - *Health protection and care*
    - *Diagnostics and sensors for prevention and detection.*

A key issue is the ability to reliably link biologically active molecules to surfaces, and this will give huge opportunities for improved medical devices and drug delivery strategies. Also important is the design of materials that mimic the behaviour of physiological systems such as muscle.

There is strong emphasis on how nanochemistry will revolutionise healthcare and pharmaceuticals, with the potential for more efficient drug delivery and reduction of side effects.

Quality of life:



The quality of life of European citizens could be enhanced dramatically by use of new materials to provide:

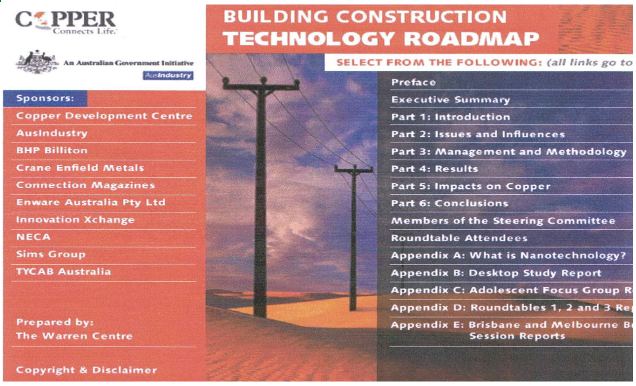
- Better communications – *mobile phones, portable computers*
- Better mobility – *more efficient and sustainable transportation*
- Cosmetic preparations - *for better appearance and protection from external environment*
- Improved nutrition – *for increasing the stability and bio-availability of vitamins and food additives via innovative and formulation techniques*
- Smart internal and external coatings – *with self cleaning properties and switchable upon changes in the environment*
- Surfaces with anti-fouling properties – *recognise and destroy pollutants and corrosion agents*
- Speciality polymers – *intelligent composite materials*
- Bio-compatible materials – *design of longer lasting batteries, and smaller and more stable sensors*
- Materials for functional clothing – *e.g. self cleaning*

Nanotechnology is forecast to have a marked impact on our quality of life, especially for cosmetics and nutrition.

Both the above reports also mention the construction industry and the benefits that new materials could have on future buildings. The following summary describes a roadmap that specifically looks at the building industry.

BUILDING CONSTRUCTION TECHNOLOGY ROADMAP

In 2004, the Copper Development Centre sponsored a Building Construction Technology Roadmap in Australia (http://www.copper.com.au/technology_roadmap/index.html).



It did not just cover copper, being more generally applicable to the requirements for the future in Western Europe as well.

To provide a flavour of the content, smart materials are considered, and two tables are worth reproducing:

Flexibility, modularity and materials

Smart windows	• Thermal, optical & acoustic control	• Integrated photovoltaics • Films incorporating nanoparticles for spectral selectivity, giving reflectivity and thermal control • Holographic / imaging projection • Organic Light Emitting Diode (OLED) embedded in conducting polymer layer in laminated windows • Switchable between transparent and opaque (e.g. SPD smart glass) • Integrally able to communicate to central control

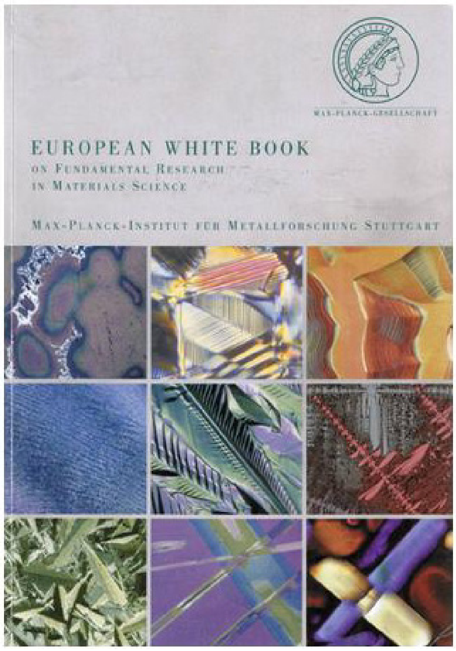
Services: Energy to and within the dwelling

Embedded technology	• Smart materials • Need to monitor many modalities • Need to crash proof house OS • Security (post 9/11)	• Embedded sensors and devices provide comfort security, lighting/energy control with instantaneous readout of energy and water usage and cost. Micro and nano sensors • Autonomous networks • Micro wireless communications between embedded devices • Energy scavenging from environment, e.g. acoustic • House OS that optimises dynamic energy profile of building in real time

BIOMATERIALS

The following sections summarise some of the main references to "bio-nano" technology that have appeared in the literature during the last few years:

EUROPEAN WHITE BOOK ON FUNDAMENTAL RESEARCH IN MATERIALS SCIENCE



This book was published in 2001 (ISBN 3-00-008806-7) and emanated from the Max Planck Institut fűr Metallforschung Stuttgart. It contains a great deal of useful information on biological aspects of materials.

In a chapter entitled "Materials: Science and Application" Professor Bill Bonfield, University of Cambridge, has written a large section on "Biomaterials: Research and Development", where he covers bone and skeletal implants, before looking at the prospects for tissue engineering.

The research priorities for Europe are given as:

- More European programmes of a scale to compete with major developments in the US and Japan
- At the same time, develop collaborative programmes with key centres in the US
- Develop a distinctive materials science approach to embrace the continuum from gene to protein to cell to biomaterial to medical device
- Emphasise the innovation of novel biomaterials and tissue-engineered artefacts, based on the biological template, for tissue and organ replacement
- Develop an understanding of the mechanisms controlling the interaction of cells with second generation biomaterials and third generation tissue engineering scaffolds
- Encourage the progression of novel biomaterials from the laboratory to distinctive clinical applications in patients by entrepreneurial technology transfer.

In a chapter on "Materials Phenomena", there is a section on "Nanomaterials", written by Professor Graham Davies, University of Birmingham, and Ottilia Saxl, Institute of Nanotechnology. There are several references to "bio-nano". They consider the move for MEMS (micro electromechanical systems) to nano devices, with biochemical sensors seen as a major development. The article reflects about the interface between the biological / medical and inorganic, focusing on molecular nanotechnology – the technology of molecular sensing and molecular recognition. The use of nanoparticles for drug delivery is summarised. Nano and microfluidics are seen as being key to the development of new drug delivery techniques, as well as being important topics for novel sensors.

In addition the section refers to the possibilities for nanotechnology applications through biomimetics. The need for better modelling is also mentioned.

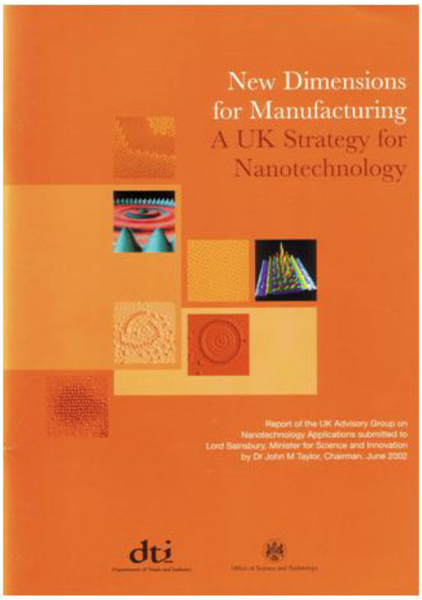
NEW DIMENSIONS FOR MANUFACTURING – A UK STRATEGY FOR NANOTECHNOLOGY

Produced in 2002, and now known as the Taylor Report, the UK Advisory Group on Nanotechnology Applications, under the chairmanship of Dr John Taylor, looked at what "success" could be for the UK.

Achievable outcomes from a successful national strategy for nanotechnology in "bio-nano" topics were seen as shown below:

Drug delivery

- Double or treble the number of postgraduates working in drug delivery
- 10 start-up businesses every year
- The first start-ups would approach profitability



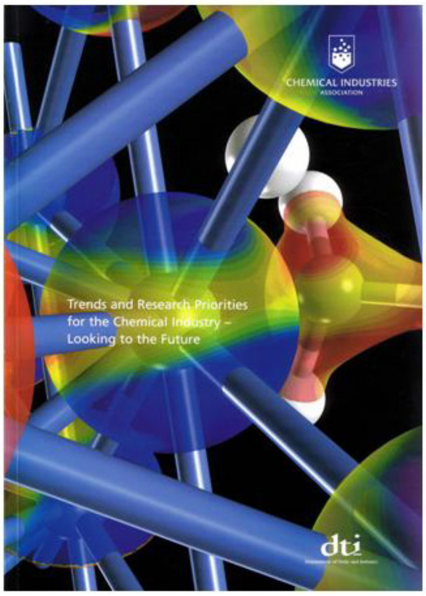
Sensors and actuators

- 10% a year growth in the number of UK graduates in nanotechnology
- 100% increase in funding for technology demonstrators
- One field trial of an integrated network of healthcare sensors in a hospital
- R&D, measured by such numbers as publications, citations and patents, to increase by 50%
- The UK's share of nanotechnology-based sensor systems grows 10% faster than our main competitors.

Tissue engineering

- 5 to 10 start-up businesses every year
- 10 additional multidisciplinary groups every year
- 2% of a $50 billion market, worth $1 billion to the UK
- 85 to 90% of UK tissue engineering companies run by UK managers
- New employment of 1,500 jobs
- 8 new products commercialised

TRENDS AND RESEARCH PRIORITIES FOR THE CHEMICAL INDUSTRY – LOOKING TO THE FUTURE



In 2003, the Chemical Industries Association in the UK produced a comprehensive review of the needs for the UK Chemical Industry (ISBN 185897 107 1). In a section on "Key Emerging Technologies", nanotechnology was an important field. Topics specifically mentioned were:

Biomedical

- Drug delivery – "lipid spheres called liposomes, which measure 100 nm in diameter have been synthesised, for improved delivery of therapeutic agents. They have been used to encapsulate anticancer drugs for the treatment of AIDS-related Kaposi's sarcoma"
- Analysis – Magnetic nanoparticles are being used in the analyses of blood and other body fluids to speed up separation and improve selectivity.

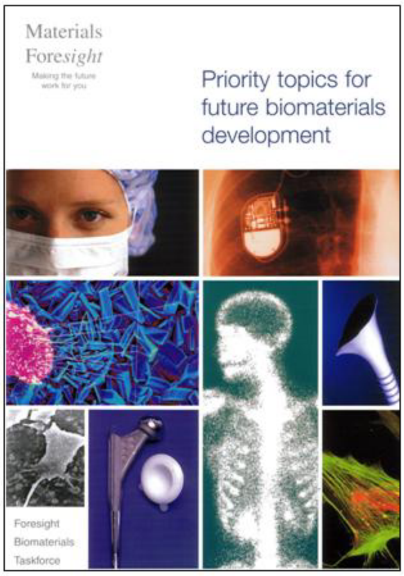
Nanosized biosensors

Specially prepared nanosized semiconductor crystals (quantum dots) are being tested as a tool for the analysis of biological systems. These dots, which fluoresce upon irradiation, will allow scientists to screen molecules as well as DNA in a quicker, less laborious manner than is possible with more traditional methods.

MATERIALS FORESIGHT PANEL - PRIORITY TOPICS FOR FUTURE BIOMATERIALS DEVELOPMENT

The UK Government's Foresight exercise has been active in addressing issues related to nanotechnology. One of the booklets, produced by the Materials Panel in 2003, considers the priorities for development in the field of biomaterials. The booklet may be found via the Institute of Materials, Minerals and Mining web site at www.iom3.org/foresight.

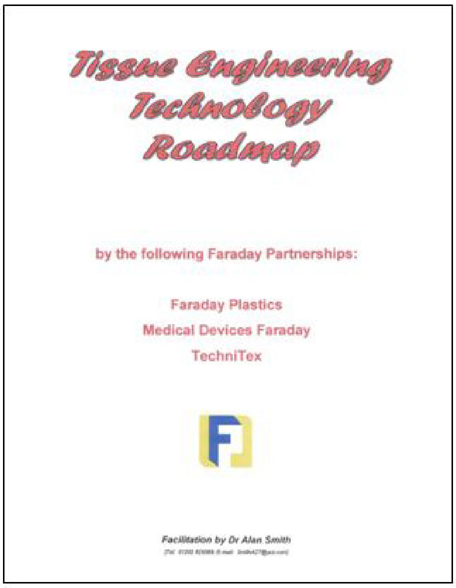
Although nanotechnology is not specifically mentioned, much of the work is directed to the nano scale. Priority research themes are given below along with some of the key points:



Mesostructured biomaterials
- Mesoscale organisation of tissues is a functionally important design feature
- Biomaterials structural organisation needs to be modelled on mesoscale tissue architectures
- Structural anisotropy will be important for achieving programmed spatial and temporal degradation of a biomaterial
- Refinement of fabrication processes is necessary prior to considering scale-up production

Self-organised biomaterials
- Natural self-assembly occurs over wide length scales and offers a model for future biomaterials
- "Bottom up" molecular self-assembly will simplify engineering and processability in bioactive response biomaterials
- Controlled drug release exploiting self-assembly will enhance function and biocompatibility
- Nanoscale delivery systems will simplify diagnostic procedures

Parallel processing and combinatorial design
- Parallel processing and combinatorial chemistry techniques should be exploited to accelerate the biomaterial development process
- Molecular probe techniques will lead to novel nano-bioengineered surfaces
- Genomic implants will help individualise implants
- Bioinformatics tools will be needed to mine growing databases



Monitoring
- Implant monitors can provide a local health check
- New optical technologies will provide greater opportunities for monitoring
- Non-invasive interrogation has become a real possibility
- High value-added products are achievable with the right sensor / implant combinations.

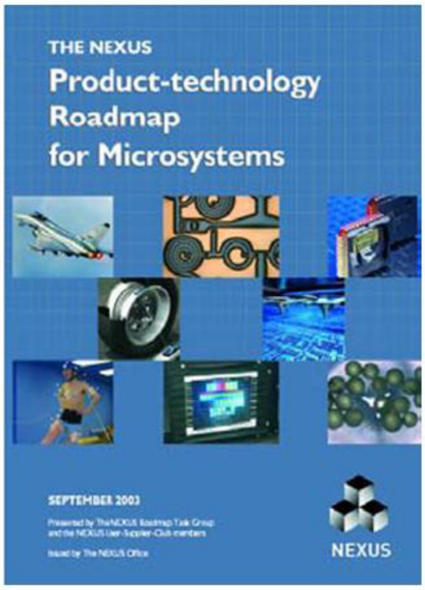
TISSUE ENGINEERING SCAFFOLDS TECHNOLOGY ROADMAP

In 2003, three Faraday Partnerships (Faraday Plastics, Medical Devices Faraday and Technitex) produced a technology roadmap focusing particularly on tissue engineering scaffolds. The report may be found at http://www.faraday-lastics.com/techroadmap.htm.

The main technical areas requiring attention were given as:
- Surface / interface between the implant and the body is the most important area needing investigation
- Combinatorial techniques to establish the effects of different material surface parameters and biological response for a range of cells needs attention.

THE NEXUS PRODUCT-TECHNOLOGY ROADMAP FOR MICROSYSTEMS

In September 2003, the second edition of the NEXUS roadmap was published and can be purchased through www.nexus-mems.com. A slide based summary is available at http://www.nexus-mems.com/documents/NEXUS%202003%20FORUM%20Roadmap%20Presentation.pdf.

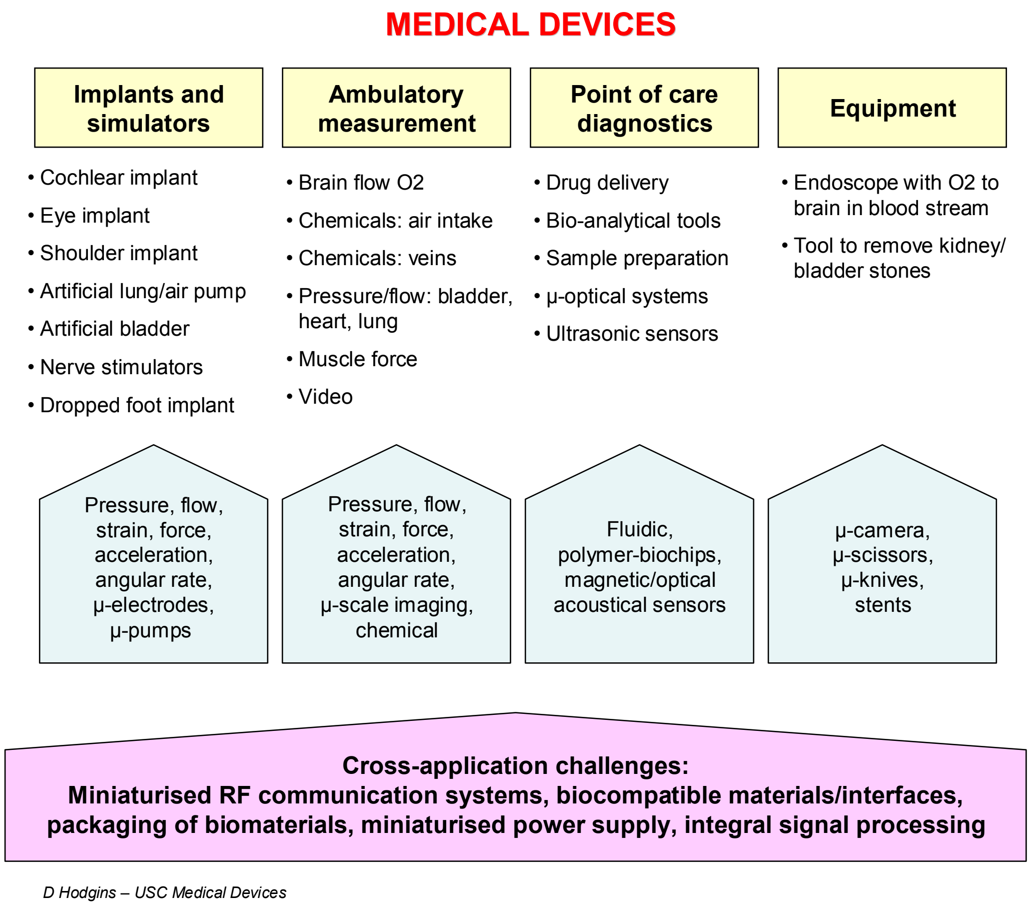


One of the slides is reproduced here to provide the future thinking for medical devices. A second slide exemplifies the device roadmap for implants. The full document is very comprehensive and well illustrated.

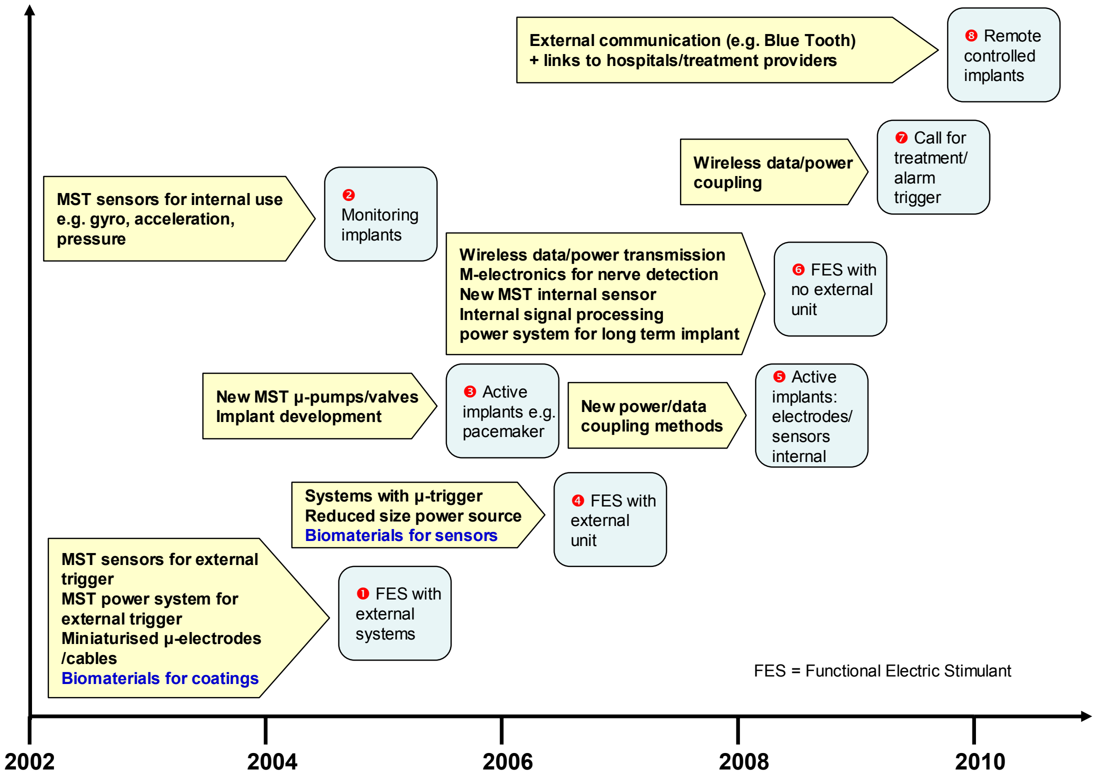
Another section deals with the developments in the pharmaceutical sector, including

- Chemical synthesis and processing
- Analysis of samples
- Sample processing.

High throughput screening is featured.

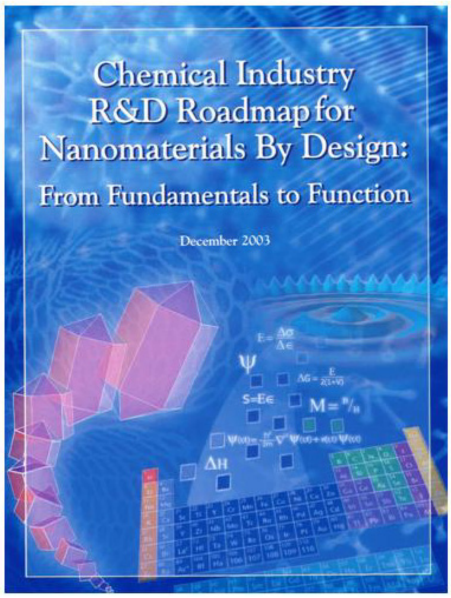


DEVICE ROADMAP FOR IMPLANTS



US CHEMICAL INDUSTRY R&D ROADMAP FOR NANOMATERIALS BY DESIGN

In the United States, the Chemical Industry Vision2020 Technology Partnership, in December 2003, produced their roadmap on nanomaterials. The 93 page report was called *Chemical Industry R&D Roadmap for Nanomaterials by Design: Fundamentals to Function*. It is well worth viewing at www.chemicalvision2020.org/pdfs/nano_roadmap.pdf.



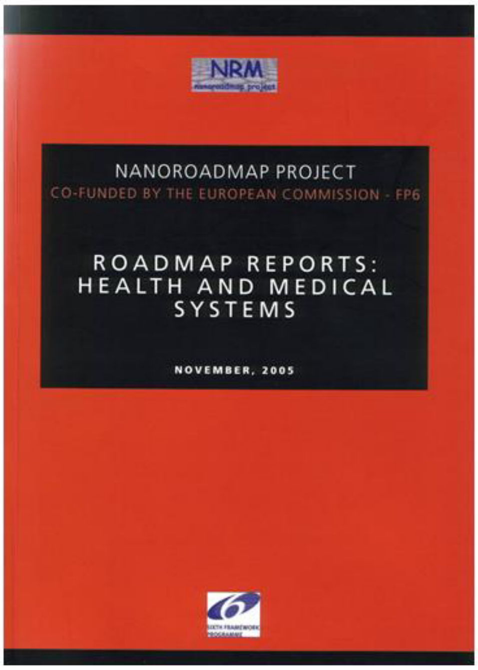
It is very comprehensive; having taken a large number of people a great deal of time and effort to prepare. The emphasis is on getting nanotechnology based products to market as rapidly as possible.

The essential elements of the research pathway to Nanomaterials by Design are described. Each topic is dealt with in some detail, giving timescales and the relative investment required. A particular feature is the inclusion of likely "impact".

Key market opportunities for nanomaterials are listed and for Medical and Health the following topics are included as priority products / processes:

Medical & Health	• Nanosensors for early detection • Nanomachines for therapy • Sterilisation and control of superbugs in medical facilities • Rapid DNA sequencing for diagnostics and therapeutics (DNA chips) • Remote and *in vivo* devices • Drug delivery (miniaturisation, bio arrays) • Drug delivery – directed delivery of actives to target sites • Prosthetics • Tissue engineering (biocompatible, high performance materials) • Diagnostic imaging • Minimally invasive surgery

EUROPEAN COMMISSION FP6 NANOROADMAP PROJECT – HEALTH AND MEDICAL SYSTEMS

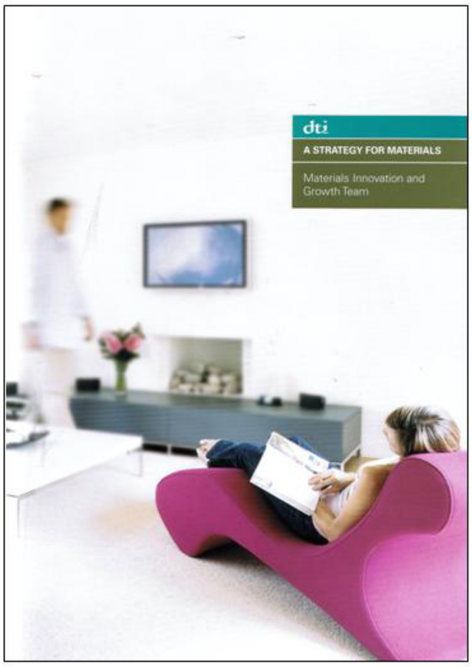


The European Commission has published a series of roadmaps in nanotechnology. One of these, published in November 2005, focused on health and medical systems (http://www.nanoroadmap.it/sectoral%20reports/sect%20report%20health.PDF).

Eleven topics were identified and then four, shown in black were selected for detailed Delphi roadmaps:

- Drug encapsulation / drug delivery / drug targeting
- Molecular imaging / biophotonics
- Biochips / high-throughput screening / lab-on-a-chip technology
- Biomolecular sensors
- Tissue engineering / regenerative medicine
- Bio nano structures
- Biocompatible implants
- Biomimetic membranes
- Functional molecules: switches, pumps, means of transportation

UK DEPARTMENT OF TRADE & INDUSTRY – A STRATEGY FOR MATERIALS



In March 2006, the UK's Department of Trade & Industry published a report directed at future innovation and growth in the materials sector (http://www.dti.gov.uk/files/file25250.pdf?pubpdfdload=06%2F651). There is a small section on medicine and healthcare. The growing need for biomaterials is highlighted, in view of the exceptional growth and development in this field. The world market is estimated at greater than $36 billion. There are major opportunities to develop new biomaterials.

Self diagnostic and self healing materials are recorded as important developments. Continued support is recommended for the development and refinement of bio-resorbable and bioactive materials.

There is also scope for materials to improve the quality of life for an ageing population, with lifestyle aids that provide mobility and facilitate self care.

PACKAGING

FORESIGHT MATERIALS PANEL – PACKAGING MATERIALS

Prior to the Material Panel's *Smart Materials for the 21st Century* report, they had set up a task force to look at the future of packaging materials http://www.foresight.gov.uk/Previous_Rounds/Foresight_1999__2002/Materials/Reports/Packaging%20Taskforce%20Report/default.html). It identified two types of "smartness" in packaging:

Active Packaging – package function triggered by some event, e.g. filling, exposure to UV, release of pressure, etc. and then continues until the process is exhausted. A number of examples were given:

- "widget" in metal beer can and glass beer bottle
- modified atmosphere flexible packaging for meat
- oxygen scavenger plastic beer bottle
- plain tinplate cans for white fruit, tomatoes, etc.

Intelligent packaging – packaging function switches on and off in response to changing external/internal conditions, and can be communicated in some way to the customer/end user. A simple definition of intelligent packaging is "packaging which senses and informs". Some intelligent packaging already exists:

- Breathable polymers for fresh-cut vegetables regulating oxygen ingress and carbon dioxide egress according to temperature
- Thermochromic ink dots indicating product at correct serving temperature following refrigeration or microwave heating
- Prescription drug bottle with bottle cap alarm that bleeps to alert users when it is time to take medicine, displays how many times bottle has been opened and intervals between openings. Bottle can be connected via modem to healthcare centre for automatic transmission of drug usage/feedback if patient not in compliance.

Examples of smart packaging under development were given as:

Active	Intelligent
Oxygen scavenging	Time-temperature history
Anti-microbial	Microbial growth indicators
Ethylene scavenging	Light protection (photochromic)
Heating / cooling	Physical shock indicators
Odour and flavour absorbing / releasing	Leakage, microbial spoilage indicator
Moisture absorbing	

Generic technologies which will play a part in the cost-effective development of smart packaging materials are:

- Novel adhesives with variable and controlled peel properties
- Lightweight materials
- Thin film/surface engineering
- Engineering of polymer structures and surfaces
- Ink and printing technologies (an area where the UK has a leading position)
- Development of smart materials generally.

It is recognised that nanotechnology will have a marked effect on packaging, enabling lighter weight packaging and packaging with improved barrier properties.

FARADAY PACKAGING PARTNERSHIP – PACKAGING ROADMAP

In March 2006, the Faraday Packaging Partnership produced a roadmap for packaging. It is available from Faraday Packaging Partnership at a nominal cost (http://www.fafadaypackaging.com). It was brought together by 68 organisations from the packaging sector through 12 workshops.

TECHNICAL TEXTILES

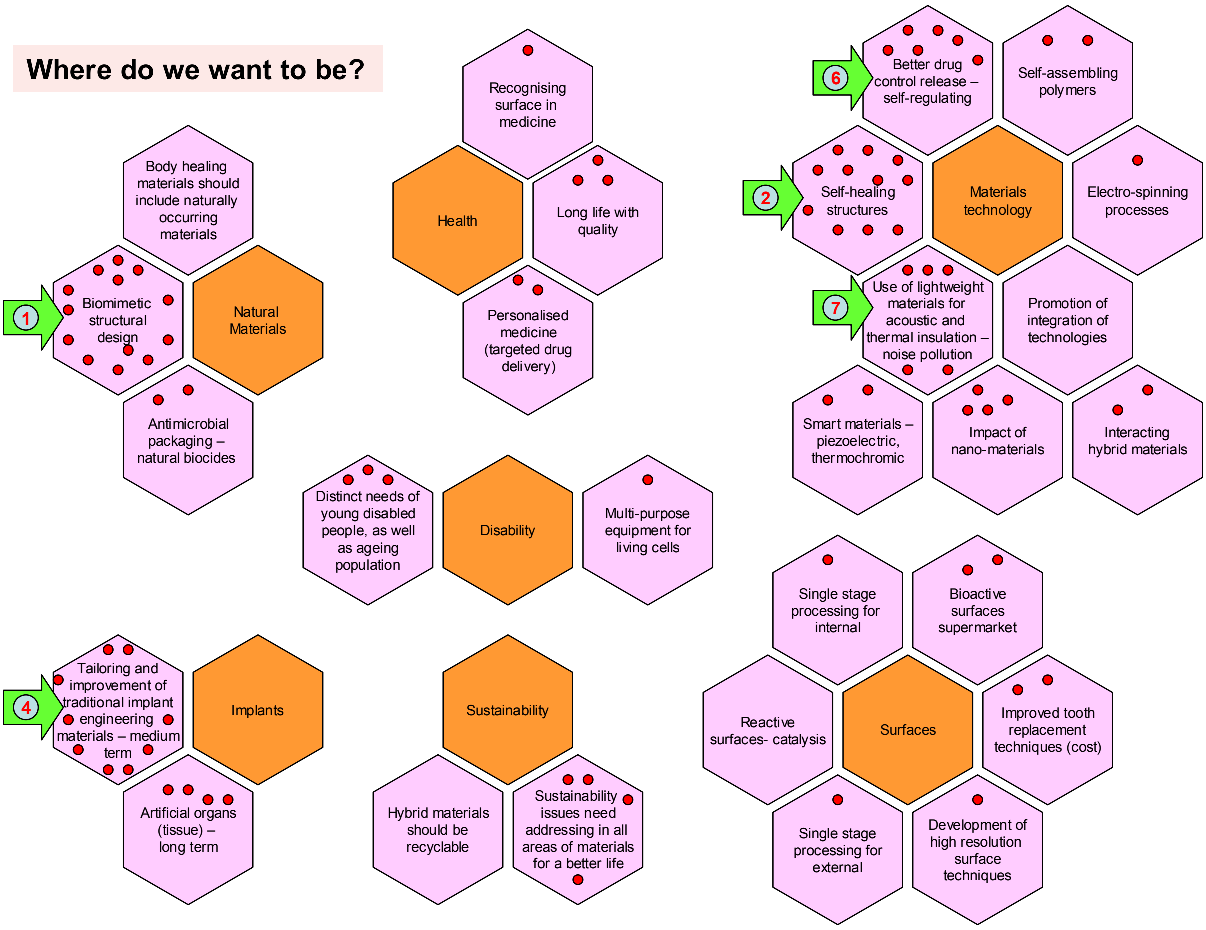
TECHNITEX FARADAY – TECHNICAL TEXTILES TECHNOLOGY ROADMAP

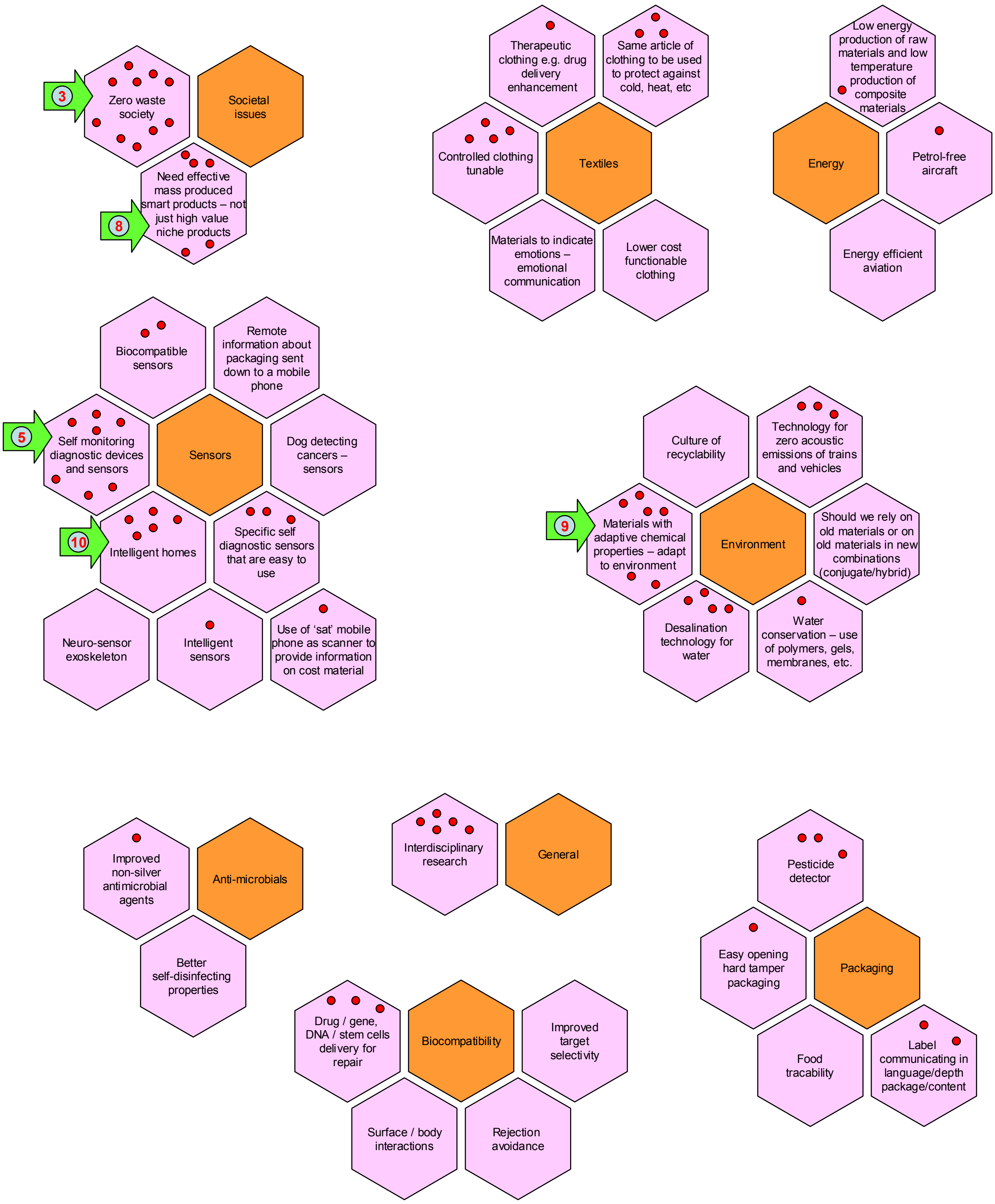
Technitex Faraday Partnership (now part of the UK's Materials Knowledge Transfer Network), has produced a roadmap for technical textiles (http://amf.globalwatchonline.com/epicentric_portal/site/AMF/menuitem.5b1d68b15d9aa2f4d50fb3f2ebd001a0/).

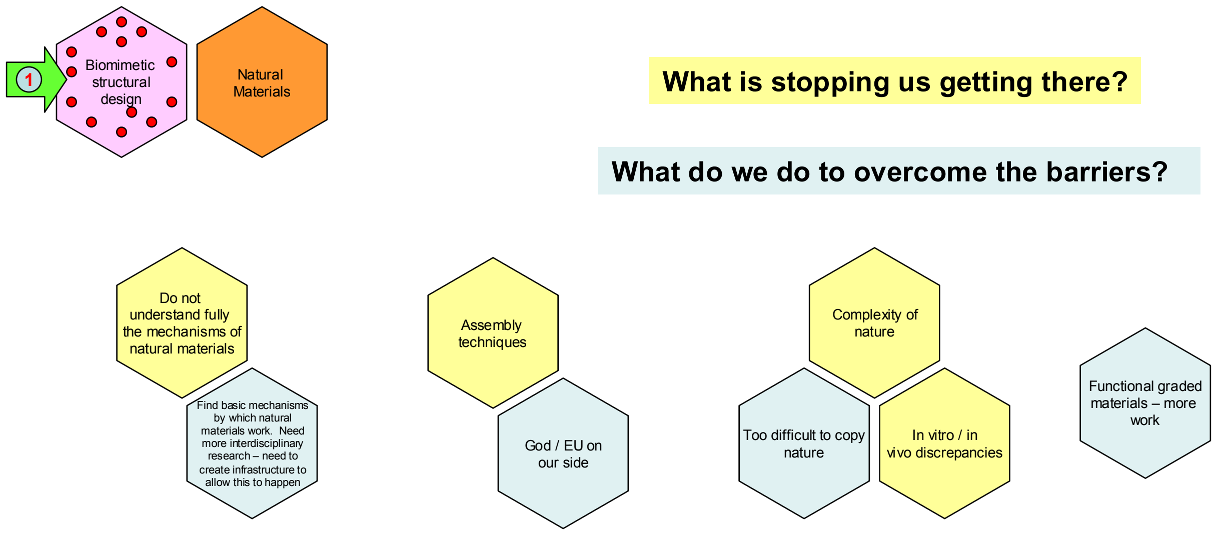
The two sections which refer to smart materials are produced below:

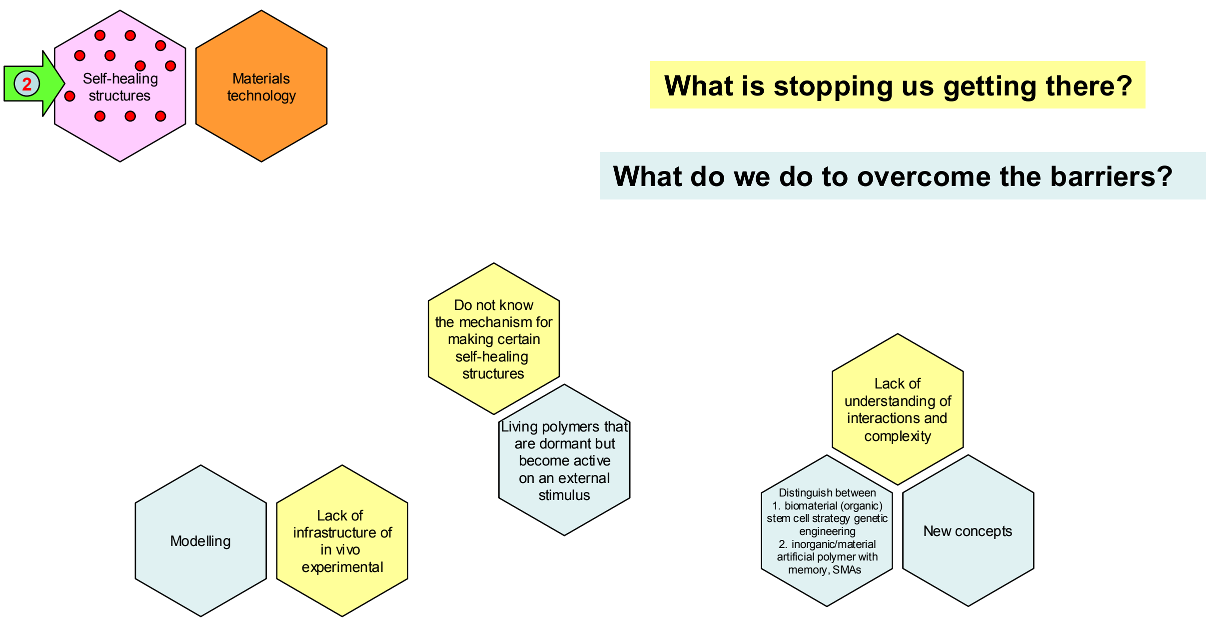
Section	Key issue	Present	2008	2013	2018
PRODUCT / SERVICE	Improved performance	Develop high margin, niche products.	Anti-allergy, anti-microbial finishes, fibres. Improved cleaning: • Soil release • Non-stain. Thermal storage.	SMART technology applications: • Biotech • Nanotech • Integrated electronics.	
TECHNOLOGY	Performance materials	Impartial evaluation of existing floor covering materials: • Microbial and dust mite issues. Air quality improvement.	New materials: • Synthetics • Bio-fibres • Conductive fibres, polymers • Nanomaterials • Regenerated wool. SMART textiles. Improved backing materials.	Sensors. Actuators. Flexible logic circuits	

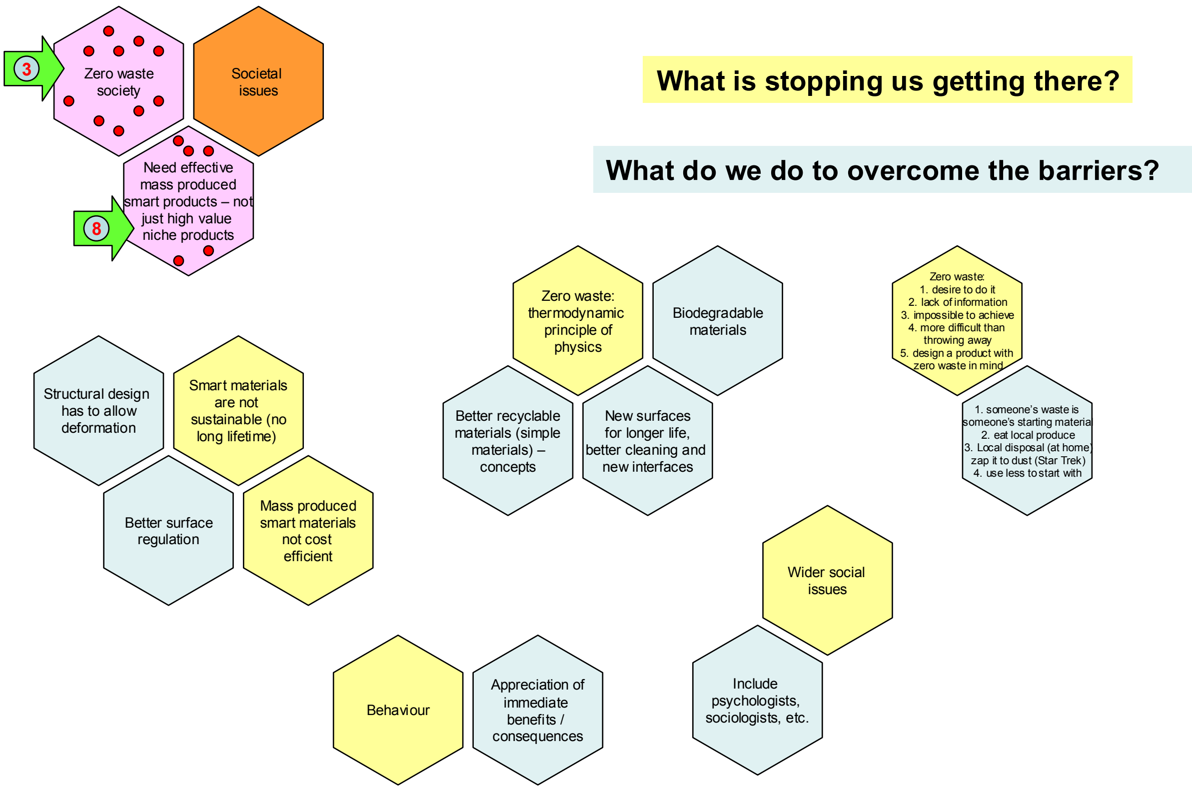
8.3 Results of Brainstorming with Hexagons

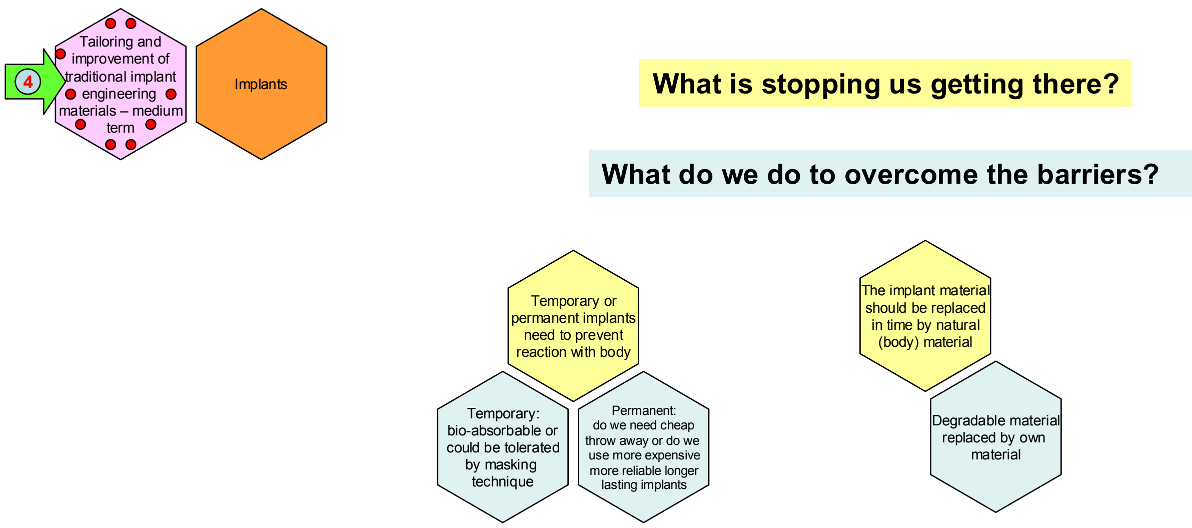


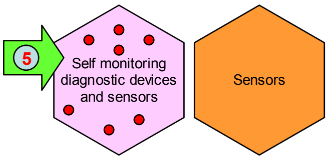

3
Zero waste society
Societal issues
Need effective mass produced smart products – not just high value niche products
8
Therapeutic clothing e.g. drug delivery enhancement
Same article of clothing to be used to protect against cold, heat, etc
Controlled clothing tunable
Textiles
Materials to indicate emotions – emotional communication
Lower cost functionable clothing
Low energy production of raw materials and low temperature production of composite materials
Energy
Petrol-free aircraft
Energy efficient aviation
Biocompatible sensors
Remote information about packaging sent down to a mobile phone
5
Self monitoring diagnostic devices and sensors
Sensors
Dog detecting cancers – sensors
10
Intelligent homes
Specific self diagnostic sensors that are easy to use
Neuro-sensor exoskeleton
Intelligent sensors
Use of 'sat' mobile phone as scanner to provide information on cost material
Culture of recyclability
Technology for zero acoustic emissions of trains and vehicles
9
Materials with adaptive chemical properties – adapt to environment
Environment
Should we rely on old materials or on old materials in new combinations (conjugate/hybrid)
Desalination technology for water
Water conservation – use of polymers, gels, membranes, etc.
Improved non-silver antimicrobial agents
Anti-microbials
Better self-disinfecting properties
Interdisciplinary research
General
Drug / gene, DNA / stem cells delivery for repair
Biocompatibility
Improved target selectivity
Surface / body interactions
Rejection avoidance
Pesticide detector
Easy opening hard tamper packaging
Packaging
Food tracability
Label communicating in language/depth package/content


1
Biomimetic structural design
Natural Materials
What is stopping us getting there?
What do we do to overcome the barriers?
Do not understand fully the mechanisms of natural materials
Find basic mechanisms by which natural materials work. Need more interdisciplinary research – need to create infrastructure to allow this to happen
Assembly techniques
God / EU on our side
Complexity of nature
Too difficult to copy nature
In vitro / in vivo discrepancies
Functional graded materials – more work


2
Self-healing structures
Materials technology
What is stopping us getting there?
What do we do to overcome the barriers?
Do not know the mechanism for making certain self-healing structures
Living polymers that are dormant but become active on an external stimulus
Modelling
Lack of infrastructure of in vivo experimental
Lack of understanding of interactions and complexity
Distinguish between
1. biomaterial (organic) stem cell strategy genetic engineering
2. inorganic/material artificial polymer with memory, SMAs
New concepts

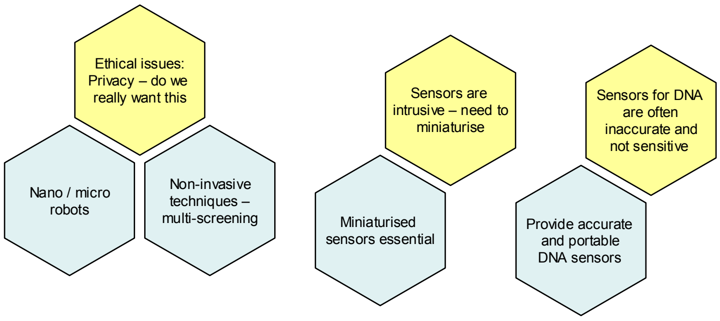

3
Zero waste society
Societal issues
8
Need effective mass produced smart products – not just high value niche products
What is stopping us getting there?
What do we do to overcome the barriers?
Zero waste: thermodynamic principle of physics
Biodegradable materials
Better recyclable materials (simple materials) – concepts
New surfaces for longer life, better cleaning and new interfaces
Zero waste:
1. desire to do it
2. lack of information
3. impossible to achieve
4. more difficult than throwing away
5. design a product with zero waste in mind
1. someone's waste is someone's starting materia
2. eat local produce
3. Local disposal (at home
zap it to dust (Star Trek)
4. use less to start with
Structural design has to allow deformation
Smart materials are not sustainable (no long lifetime)
Better surface regulation
Mass produced smart materials not cost efficient
Wider social issues
Include psychologists, sociologists, etc.
Behaviour
Appreciation of immediate benefits / consequences

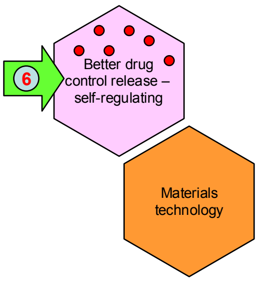

4
Tailoring and improvement of traditional implant engineering materials – medium term
Implants
What is stopping us getting there?
What do we do to overcome the barriers?
Temporary or permanent implants need to prevent reaction with body
The implant material should be replaced in time by natural (body) material
Temporary: bio-absorbable or could be tolerated by masking technique
Permanent: do we need cheap throw away or do we use more expensive more reliable longer lasting implants
Degradable material replaced by own material



What is stopping us getting there?

What do we do to overcome the barriers?





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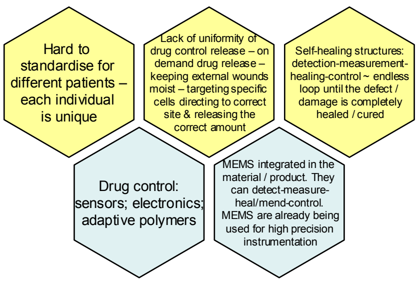

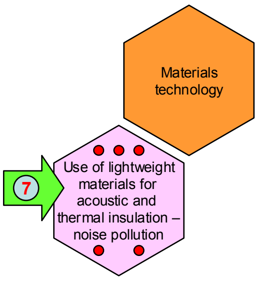

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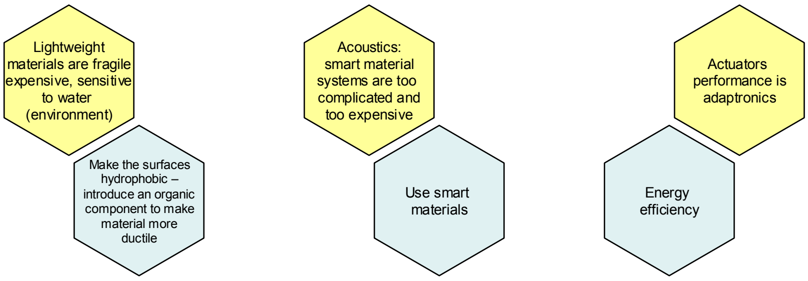

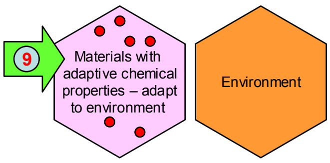

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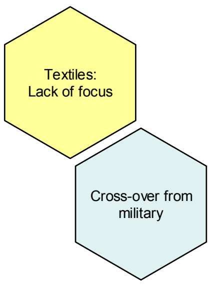

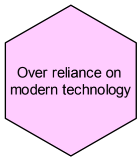

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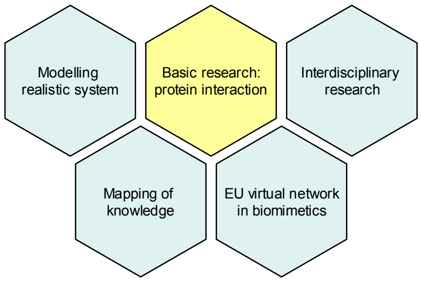

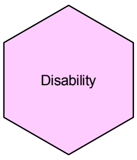

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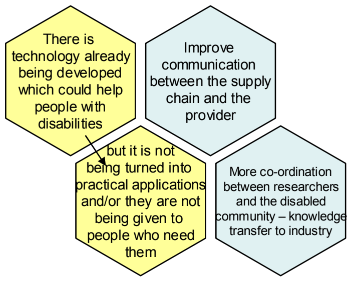
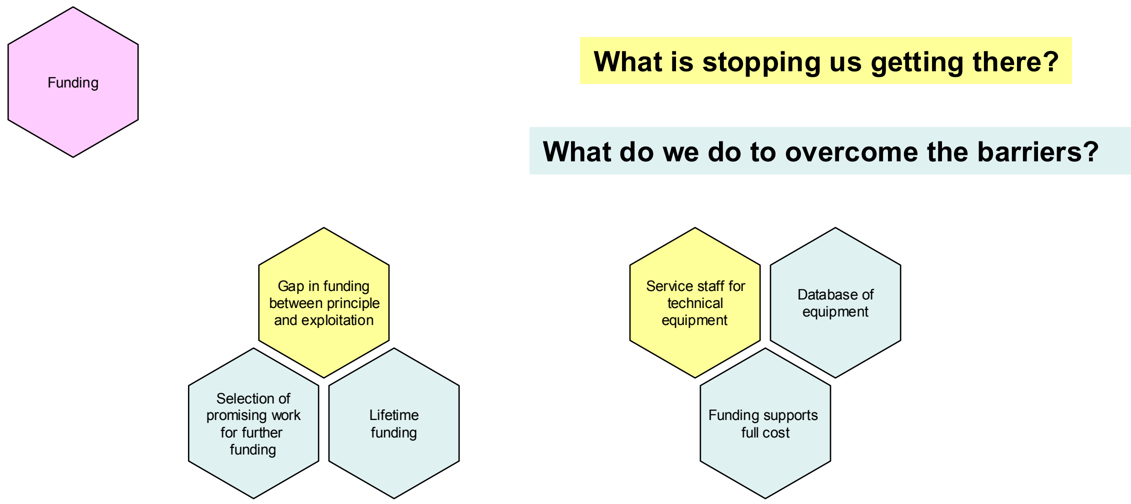
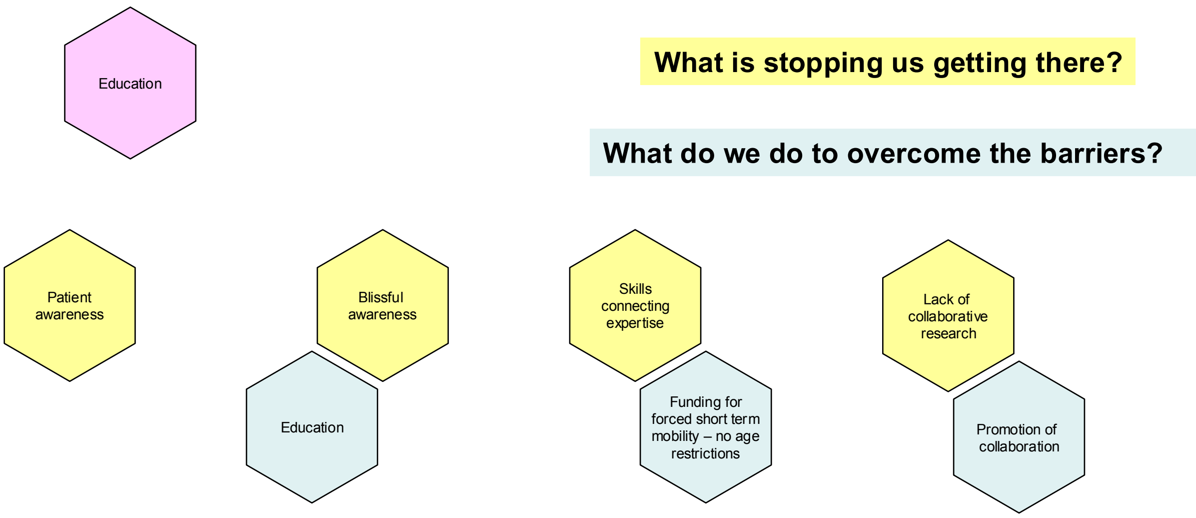



Funding
What is stopping us getting there?
What do we do to overcome the barriers?
Gap in funding between principle and exploitation
Selection of promising work for further funding
Lifetime funding
Service staff for technical equipment
Database of equipment
Funding supports full cost


Education
What is stopping us getting there?
What do we do to overcome the barriers?
Patient awareness
Blissful awareness
Education
Skills connecting expertise
Funding for forced short term mobility – no age restrictions
Lack of collaborative research
Promotion of collaboration