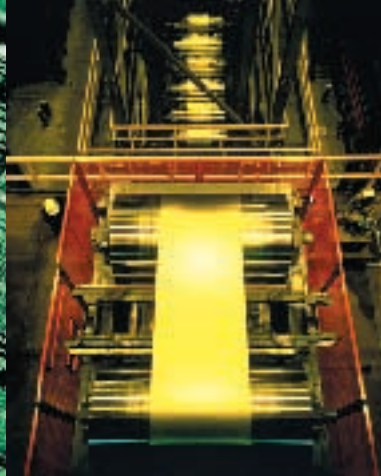
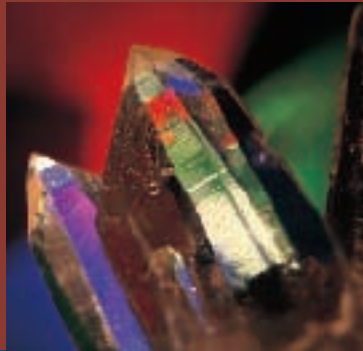


Foresight

Making the future work for you

Materials: Shaping our Society



Materials Panel

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The views expressed in this report are the personal opinions of panel and sub group members and do not represent the official views of the organisations they represent, the Office of Science and Technology or the Department of Trade and Industry.

Summary of Key Recommendations

The panel believes that there are certain big issues that affect the whole materials sector and beyond and others that are more focused on individual industries or interest groups.

In this report we have therefore highlighted the following areas as needing specific and proactive attention for the future well being of UK industry which rely on materials for competitive advantage within a global and sustainable environment.

- The need for a unified and forward looking UK Materials Strategy.
- The requirement for a continuing supply of innovative materials specialists to service both mature and developing supply and user industries.
- The need to organise and co-ordinate materials research and make sure the outputs are available to emerging user industries.
- To promote Materials Modelling for End Use Applications.
- The need to establish world class groups and networks capable of exploiting the potential of nanotechnology in specific areas.

All these will require significant and focused resources if the UK is to hold its position as a leader in high added value design.

The details of these recommendations are expanded upon in Section 2 of the report.

1 Introduction



Professor John Wood
Chair, Materials Foresight Panel

Welcome to this report from the Materials Foresight Panel. It describes the progress that the previous and current panel has made since the original report was published in 1995. From both the style and context it can be seen that things have moved a long way since that original report and the recommendations it contained. This present report seeks to give a glimpse at the way Materials Foresight has developed and to give an indication of the widespread ownership of the Foresight process by the Materials supplier and user communities.

The Materials Panel has operated in a slightly different way to many of the other sector panels. This is because we did not see a discontinuity between the first and second rounds. Some of the panel have remained the same (including myself as chair) and we believe that in the latter part of the last round we had started to see some embedding of the Foresight process among the community we represent. Indeed it was a deliberate policy to create a small panel whose main job was to encourage and foster Foresight activities elsewhere. To this end we have been encouraged with those groups who have taken up the challenge, exercised by groups that have struggled and disappointed by groups who believe planning for potential future scenarios is not important to them. It was always intended that this report would be a compilation of the activities of these groups while extracting the main common messages. It will therefore appear less unified in structure and content than had just the panel written it. Also this self-selectivity means that certain key sectors are not covered as fully as they should be. The panel is keenly aware of this and will spend time trying to encourage groups in these sectors to become involved.

In the second half of the last round, the emphasis of all panels was on engaging the community from business leaders to the general public. This report will show how this has been achieved. Regular "consulting the community" days have been held to which interested parties have been invited. The response to the sessions has been mainly positive, as we have sought to broaden the minds of attendees and especially to help them appreciate the bigger picture and to "think outside the box". I remember a steel person mentioning that he had not realised the world was such a complex environment, and few can forget the banter that took place when Liz Mills from the Ageing Population panel harangued the attendees for their lack of response to the problems older people face.

Attempts to engage the wider public have also been encouraging. The publication "Tomorrow's Materials" was originally intended to engage decision-makers in industry and elsewhere in the impact that new materials would have on their activities in the future. Colin Humphrey's and his team did a first rate job in producing the first edition. It was soon realised that this could become a superb teaching resource if extra effort was put in to make it acceptable to schools and we were delighted that "Tomorrow's Materials for Schools" was then produced with teacher's notes and distributed to every secondary school in England and Wales. Building on this, a stand was mounted at the "Tomorrow's World Live" exhibition in 1999. Few can fail to remember how the Minister of Science was persuaded to insert his hand into a new cricket batting glove made from composite

materials as a ball was hurled at him by eager students from the Kirby Centre in North Notts. At that stand the Institute of Materials signed up many schools onto its Schools Affiliate programme and some of these have been the basis of our ongoing follow up activities.

By contrast, efforts with Trade Associations, Sector Organisations and Professional Institutions have required a more determined approach. This has taken up much of the panel's time but those groups that have taken the plunge have seen it as an extremely worthwhile exercise. The number of Trade Associations and the service they offer to members has been of concern to the panel. Very few see that planning for the future is one of their functions. There is a drastic need for an overhaul of Trade Associations relevant to the materials community or at least recognition that some are Foresight active.

There have been a number of common lessons from those groups that have become engaged in Foresight for their members. The first is that there must be a champion from within the sector who will take things forward. The second is that the exercise is mainly for the benefit of those who participate rather than trying to appease a governmental whim. The third is to ensure that the various factions that have inevitably formed over the years start to see that a common approach to the future is in all interests and not a fight within the community. The final aspect is to ensure that the exercise is an ongoing one, which does not end when a report is produced. The detailed findings need to be disseminated and constantly refined in the light of changing trends. It is inevitable that the outputs from these groups have a much shorter time horizon than those that are commonly associated with the Foresight process.

The panel has identified some key areas of future development where there was no obvious focal point at the time of starting. Such a case is the report on "Opportunities for Industry in the Application of Nanotechnology." Since the inception of that report, the Research Councils have announced initiatives and the Institute of Nanotechnology in conjunction with other organisations has taken the issue further. Another case in point has been the creation of a group, supported by the DTI, to advise on strategic issues in biomaterials. However we are aware that there are areas where little or no work has been done. A considerable amount of time has been spent trying to encourage a view on "Technical Textiles," materials for "information storage" and "energy storage" for example. While the first of these is beginning to find some momentum as a result of DTI funding, the second has withered after a town meeting and the third will be a high priority in the next stage of the Foresight process.

From all this you will not expect this report to be a fully analytical document which is even in its coverage of all the issues. The original Foresight process was based on the Japanese experience of using Delphi forecasting. While this was valuable to some extent, it was not widely popular with the community and seemed distant to most people. We include a section revisiting the main recommendations from the first round. However it is salutary

to see how the nature of the global economy with respect to materials has changed even in that short time and places the emphasis of our main recommendations on more leading edge technology rather than just the increase in the performance of existing materials. This has largely been governed by the clear decline in traditional manufacturing industry within the UK and especially the question whether it is necessary or desirable to produce primary high volume, low cost volume materials with the associated problems of environmental impact and developing a sustainable culture. As many of the primary producers are global manufacturers, the choice as to point of production is one that will increasingly be made with little attention to historical factors. Since the first report we have seen increasing mobility among this sector with some key companies announcing their intention to produce more offshore in the future.

Thus, in summary, this report attempts to provide a snapshot of what is happening in Materials Foresight in the UK at the end of the year 2000. In view of the methodology adopted it is neither exhaustive nor uniform in its content. For, example, many of the sections has been written by the sectors themselves. There has been little attempt to try and create a uniform genre in the interests of the reader. Our motto has been "Let the sectors speak for themselves!"

In the main this leads to fairly detailed recommendations that are specific to that sector. We have tried to put in short summaries of these, but for those who want more detail your attention should go to the Foresight website (www.foresight.gov.uk) where many of the detailed reports are stored. It was not the intention to load this report with reams of detailed analysis.

Working with Associate Programmes such as those delivered by Professional Institutions and Research and Technology Organisations (RTOs) has been rewarding, although at times the community has become confused as a result of overlapping initiatives. This has largely bedded down. The Institute of Materials has looked at some of the cross cutting thematic themes and one of the key successes associated with issues on the quality of life has been to invoke dialogue between the commercial, industrial and academic communities who rarely find common ground to share experience. The Institute has now formed networks that meet to discuss these issues and in addition to such continuing programmes we see new ones being initiated in the materials field (at RAPRA and NPL for example).

During the course of this round, considerably more attention has been focused on delivering Foresight regionally. Professor George Smith, a member of the Materials Panel, has fostered one success. Professor Smith has set up a series of team based design projects for materials and engineering students at Oxford University, on the theme of 'Aids for Independent Living'. One of the first projects is the design of an ultra-light weight wheelchair; another involves the development of impact absorbing protective clothing to reduce the risk of hip fractures if an elderly person falls over. The project arose

out of the interaction between two Foresight groups, the Materials Panel and the Ageing Population Panel. The county Older People's Panel, Social Services Department, and voluntary organisations in the area are actively collaborating in these projects, which have already attracted commercial interest.



"Students at Oxford University work on a wheelchair design project"

It goes without saying that we hope the report encourages, stimulates and results in further actions for the good of the UK and its citizens. In the end, the success of Foresight depends upon implementation rather than fine words.

2 The key issues

A Question of Definition

There has been considerable debate about what the term “Materials” covers and whether it is a distinct sector. The fact that materials issues pervade all aspects of our lives is acknowledged. Whether it is modern medical procedures or the phenomenal changes in telecommunications, all depend on materials developments. While it was relatively easy to define materials in the past according to large scale primary supply industries (e.g. glass, steel etc) this is now no longer the case as we move towards materials user industries. However our consultations all reveal that there is a need for a “materials specialist” in industry who can bring their considerable overarching knowledge early to the design process in order to improve innovation and give a competitive advantage to their products. There are numerous examples in those companies who have won “Millennium Product” awards to demonstrate the effectiveness of this approach.

It is not surprising, therefore that many see a “materials education” being of considerable value, especially for leading teams of more focused specialists, since the ability to transcend between pure and applied science within a business development context is inherent to such an education. In other words, it is precisely because it is overarching and difficult to define that it is so useful. As the core materials supply companies reduce their activities in the UK, it is essential that there is a critical mass of materials expertise available to the emerging and growing user base.

United We Stand

■ A unified UK materials support strategy is required to stop the random dispersion of resources via different ministries. This needs to be an ongoing activity that can be undertaken under the Foresight banner given appropriate ministerial backing. Such a strategy would bring together various sectors to look for efficiency gains in working together and would also overview the requirements for the various national laboratories and dissemination organisations.

■ The panel fully supports the view that Research Councils and Universities should be allowed freedom to pursue long term and speculative research. However, with the decline in large corporate research laboratories in materials in the UK, attention should be paid to how existing and new companies can have their research needs satisfied, given that the current resources are scattered among various institutions. It is proposed that a one stop Materials Research Centre should be created to co-ordinate the national and local activities of research providers including RTOs and universities and also provide a brokerage service. Local point of contact is required for SMEs and the proposed Regional Manufacturing Centres in conjunction with the Engineering Employer’s Federation should be considered for this purpose.

People Are Critical

As the large scale primary materials supply industries decline in influence in the UK, further attention is needed to ensure that the impact that good materials knowledge has on end user design needs is realised. This requires a focused critical mass of expertise available to all product designers especially those in SMEs. Attention should be paid as to how this expertise can be delivered within a regional development framework using existing research capabilities within universities and RTOs.

The Royal Academy of Engineering's report "The Universe of Engineering" has pointed out that there is a core "materials skill base" along with IT that is generic to the whole engineering process. With the rapid development in materials science and engineering, which impact on all aspects of society, a coherent life long education and training programme for both specialists and generalists needs to be developed to ensure UK industry remains competitive in the future.

A coherent and integrated approach to delivering materials education from primary schools onwards is required if responsible citizens are to take their place in a sustainable society. A "throw away" culture must be a thing of the past. Action is required to bring together all the parties involved to ensure a coherent strategy. This includes the various ministries involved, in addition to industry and public bodies. This strategy might be delivered via the Learning and Skills Councils.

A thorough survey of international "best practice" in materials education should be undertaken in the light of upcoming changes in the way higher and continuing education is delivered in the future. This may be embedded within a wider analysis of science and engineering education, which should seek ways to cut across established discipline boundaries. The DfEE should carry out such a survey in conjunction with institutions such as the Royal Academy of Engineering and the Royal Society who can bring a holistic approach to the problem at the highest level.

The panel fully supports further development of "Young Foresight" in engaging young people in innovation, which often depends on new materials developments. Further impetus for such initiatives and related activity is required.

Modelling Matters

Predictive materials' modelling is growing in importance. By guiding choices, it cuts down on experimentation and costs and speeds up time to market.

The UK has significant strengths in modelling, notably polymer modelling. But there are gaps and there is no room for complacency in this rapidly expanding field.

Benefits are limited by "brainware", not hardware or software. The ability to frame the problem and understand the limitations of a model are crucial.

Modelling teams must be stable enough to build experience and confidence in modelling techniques. With the demise of large, central laboratories there is a need for a renewed national focus. Government should take the lead in establishing such a (virtual?) centre and give careful consideration to encouraging industry and academic involvement.

Nanotechnology- the new industrial revolution?

The Panel endorses the continued support of government and academic funding in the broad themes of nanofabrication, nanometrology, functional nanotechnology, nanomechanical devices and machines, molecular nanotechnology, particles, clusters and catalysis, nanostructured materials, and “extreme” nanotechnology.

However, it believes that three areas are deserving of special consideration.

These are:

- Nano-fabrication
- Molecular nanotechnology at the biological/medical/functional materials interface
- “Extreme” nanotechnology

The UK infrastructure for nanotechnology is in general lagging behind that provided in the other major industrial countries. Serious spending elsewhere in the world could cause the brightest talent from the UK to look elsewhere for support. Centres of expertise need to be established which will cater for and nurture research. Whether these are real physical entities or virtual centres is not debated, only that they exist. The establishment of such centres will drive the production of trained personnel in these new techniques and technologies. This needs to be underpinned by a major awareness campaign aimed at children in primary and secondary education. Nanotechnology is an exciting area; and will inspire a future generation of scientists and engineers.

The application of nanotechnology is well developed in the US and several countries in Europe, and is beginning to find niche markets in the UK economy in products and goods which are used in every day life. The fact that such goods use nanocompounds or nanostructures is not well publicised. An awareness campaign needs to be undertaken to improve both better public and industrial understanding of the power of nanotechnology for the present and future health of the UK economy.

Centres - Real or Virtual

In many of the recommendations above, the idea of a co-ordinated activity comes to the fore. The main reason for this is that the panel believes that much good work is being done in the UK by industry, research institutions, government laboratories and universities.

The idea of having new geographical centres where all the technology and information exists has not met with widespread support in view of immediate past experience with research centres. Likewise experience with virtual centres means that they remain just that. In order to support new and emerging companies that require specific research information which is accessible easily it is proposed that a model based on some form of central co-ordination using high level personnel is adopted. An important feature here is the need for personnel who are respected by all parts of the supply chain. For example, in modelling, it must be people who can talk intelligently with the software companies and express an informed view to potential funding agencies. The “centre” would network all the relevant research and information organisations that already exist and provide local contact via the proposed regional manufacturing centres or other regional conduits. The co-ordination role would also identify key future needs and try to ensure that the necessary capability becomes available. In this way, critical mass teams could be formed for specific end user needs. Critical to the success of this model is the ability to be able to deliver in a customer friendly way locally. The links with local delivery services including the Materials Information Service are therefore extremely important.

Critical Areas for Further Activity

In addition to maintaining and increasing the momentum of the existing activities, the panel will initiate analysis and actions in the following key areas:

- Sustainable Construction Materials
- Energy Storage Materials
- Sensors
- Technical Textiles
- Functional Materials

Steps have already been undertaken to take these issues forward. For example in the case of Sustainable Construction Materials a joint initiative between the Materials and the Built Environment and Transport Panel is planned. It will also be necessary for the Panel to continue to review the recommendations made in individual Sectoral Studies and to take an overview of which of these are critical for improved quality of life and wealth creation.

Sustainable Construction A Case Study: The University of Nottingham Jubilee Campus

The Nottingham University Jubilee Campus was opened to students in 1999 after a 2-year design and construction programme. Built on what was once Raleigh's bicycle factory, the design brief required that buildings should be naturally ventilated wherever possible and utilise low levels of energy. This had been achieved, in part, by coupling a super-efficient ventilation system with photovoltaic power so that the energy consumption of the fans is provided by a clean, renewable source.



CAMPUS LAYOUT

The main campus buildings comprise three faculty buildings and the central teaching block consists of three wings connected by atriums and courtyard gardens. The main buildings butt up against a new lake beyond which is a developing wildlife belt.

VENTILATION

Ventilation is based on a low-pressure mechanical fan system allied to heat recovery that gives improved energy performance compared to natural ventilation. This system also ensures that fresh air reaches all parts of the buildings and atrium-linked wings.

Incoming air, taken at roof level to avoid street level pollution, is passed over electrostatic filters via shafts to floor diffusers in the teaching rooms. Air leaves through the corridors to rooftop air handling units, for heat recovery or evaporative cooling, prior to being expelled through revolving steel cowls that use the wind to extract exhaust air.

The mechanical ventilation system circulates 100% fresh air all year. The fans require 51,000kWh of electricity and this is provided by 450m² of high efficiency monocrystalline photovoltaic cell built into the roof of the atriums.

HEATING, COOLING AND LIGHTING

The buildings have integrated heating and cooling systems. Both systems use energy stored in the fabric of the buildings and both make use of thermal wheels in the air handling units to regain energy that would otherwise be lost outside.

The thermal wheels recover 84% of the energy in exhaust air and use it to heat incoming fresh air to 18°C. This only needs supplementing with a gas-fired boiler when the external temperatures drop below 3°C.

When day temperatures rise above 24°C, a night cooling system moves fresh air over the building fabric which makes the teaching rooms more comfortable the following day.

Insulation is achieved by the use of a recycled paper product for the walls and polystyrene for the floors and roof. The roofs of the faculty buildings have 50mm of earth on them

planted with a grass-like mixture of moss and lichen. This serves to stabilise the roof slabs and insulates against thermal gains as well as blending in with the landscape and wildlife areas. This theme is further enhanced by the use of external cedar wall claddings. This wood comes from certifiable sustainable forestry in Canada.

The lighting system aims to bring in natural light where it is needed while reducing internal gains and cutting glare. This is achieved by using white-surfaced louvres on east and west facing windows in tandem with internal light shelves and monodraught light tubes to guide light into the centre of teaching areas. The buildings do not have manual light switches; an intelligent management system linked to passive infrared movement detectors in every room ensures minimal energy wastage.

In summary, the Jubilee Campus uses no more electricity than naturally ventilated buildings, has minimal energy loss in winter, stays cooler in summer and provides significantly improved comfort all year round.

The previous panel had already published a report on sensors for manufacturing ("Sensing the Future"). It is now proposed to look at the issue of materials for sensors and their method of manufacture. Representatives have been invited to join a task force which will look at the future of micro-electro-mechanical sensors (MEMS), bio-sensors and other sensors that will be critical for crime prevention, environmental impact, health monitoring etc.

The panel has been exercised about the apparent decline in the UK's Textile industry. Ongoing discussions within the DTI have led to the creation of an initiative on Technical Textiles. The panel perceives that further analysis and support for this sector is urgently required to follow up the recent report of from the British Apparel and Textile Confederation "A National Strategy for the UK Textile and Clothing Industry". This emphasised the need for more university activity and research and the panel were pleased to hear of the announcement to create a Faraday Partnership in Scotland on Technical Textiles (TechniTex) in which Heriot-Watt University, UMIST, University of Leeds and the BTTG are partners. Under the aegis of TechniTex, a wide range of R&D, production and networking oriented activities will take place between the four partners or between any one of the partners and outside bodies such as HEIs and technical textile companies.

The Panel will be monitoring the progress of this centre in order to ensure that all aspects are covered and to provide support for further activities including encouragement of overseas missions.

The area of Functional Materials has been a problem for the panel. The speed of development coupled with the fact that most developments are led from overseas has made it difficult to find people who could take this issue further with meaningful outputs. It is acknowledged that the UK still has a good basic research base in functional materials and this provides good training for many scientists and engineers. The panel is mindful that the pull through to new products could be enhanced and will be setting up a task force to look further at what additional Foresight can make.

In addition to the specific areas mentioned above, the panel has commissioned a study to try and identify the key lessons for successful spin out and start up companies who rely on materials innovations. The high risk and, often, long lead times for market development coupled with the fact that materials based companies seldom drive supply chains, means that there are specific lessons that can be learnt from current companies. The report is expected early in 2001 and discussions have taken place on the best way to disseminate output from this study in an innovative way.

3 | Review of actions resulting from the previous Materials Report

The first Materials Panel report (*'Progress Through Partnership: Materials'* HMSO 1995) was a groundbreaking attempt to focus attention on key issues for the future. Undertaken within a very tight time schedule using the methodologies developed in Japan it made a number of key recommendations that have stood the test of time. Rather than just ignore these, it is useful to look again at them and see what has happened as a result. The fact that the Materials panel is now looking at much wider issues and employs different methodologies should not detract from this exercise.

It should also be borne in mind that the panel was under some pressure to make firm detailed recommendations for increased and decreased investment. Under these constraints the following two key recommendations were made:

"Increased investment in the continuous improvement of materials and processes is the highest priority to emerge from the Materials Technology Foresight Initiative."

And

"Materials and processes which protect or remediate the environment and which can save lives and alleviate suffering should be targets for investment."

In addition to these key recommendations the following summarised the outcome of the report

That substantial increased resources should be devoted to research, development and exploitation in the following areas:

- Models which relate materials composition, structure, process parameters, end product performance and design; models need good data which will be generated from improved testing and evaluation methods
- Materials to improve sensors and devices
- A new generation of biomaterials which encourage and enhance the restoration and repair of body tissue function
- Efficient processing technologies and automated process control including enhanced robustness of processes to reduce costs and increase customer satisfaction; processing technologies which have a lower impact on the environment
- Lighter weight materials and materials based weight saving technologies for specific applications in the aerospace, automotive, off-shore, packaging and construction industries
- Higher temperature materials for specific applications in the aerospace, automotive, electronics and power generation industries
- Processing techniques to convert existing high temperature superconductors into commercial products.

That there were a further three priority targets which also warranted consideration for the investment of research and development funds

- Better materials to serve the needs of the mobile IT and telecommunications industries such as materials for use in improving opto-electronics applications and batteries
- Rapid, low cost and durable joining techniques which contribute to more competitive manufacturing and products
- Surface engineering science and technology, which improves significantly the competitiveness of specific products and processes.

That there was not evidence to justify further increased investment in the following areas

- Monolithic ceramics for dynamically stressed applications
- Work on warm superconducting materials not addressing processing and application. Not more than 10% of the resource on superconducting materials should be devoted to the discovery of new even higher temperature superconductors.

To achieve the objectives outlined above the Panel developed further recommendations for:

- Additional funding of materials research and technology to support the continuous improvement of materials and processes and the development of materials and processes which improve the environment or save lives. It also addressed the need for industry to help target and access this research and for simple partnership schemes to encourage exploitation by industry.
- Increasing the involvement of industry in taking forward the results of Foresight by improving the integration of supply chains, including fundamental underpinning research in universities and research institutions through manufacturing to end. The Institute of Materials was invited to become a 'product champion' for Foresight and co-ordinate the dissemination of knowledge with industry, other utilities and trade associations. Partnership programmes and strategic alignments involving mutual dependency on the part of industry and research suppliers should be supported through rapid and uncomplicated funding systems by Government Departments (including Funding Councils) working in partnership to meet their respective goals. Government also needed to target individuals in industry, from the boardroom downwards to change attitudes where necessary to research and development and innovations, where appropriate, and to take forward the results of Foresight.
- The need for funding and research assessment methodologies to give strong support to multi-disciplinary science and technology. In this context a review of the current research assessment procedures and funding methodologies currently adopted by the Funding Councils was recommended. Support for regional centres of excellence was highlighted.
- Gaining access to and utilising results of research conducted in the public domain within and without the UK through a co-ordinated science watch activity. It was recommended that this be taken up by the DTI.

Retaining flexibility in the UK science base to respond to an uncertain future by:

- i) Improving and maintaining a strong materials science and technology base.
The panel strongly favoured schemes which encouraged substantial funding for basic research and provided a linkage of the individual and/or department to applied research and industrial needs.
- ii) improving the training of materials scientists at degree level by restructuring science and engineering courses to include two years of basic science and engineering followed, by those that wish to pursue materials science and technology, by two years of specialisation in materials

Some of the activities relating to these recommendations are recorded more fully elsewhere in this report (for example in the section on steel). The following are a brief summary of the responses and actions pertaining to these recommendations.

Modelling. A full report has been produced by a group chaired by Professor Marshall Stoneham (to whom a debt of gratitude is owed) entitled "Predictive Modelling of Materials in the UK." A town meeting had been held prior to publication to discuss the emerging issues that had been identified. This was heavily oversubscribed and it will be the intention to continue to run further meetings to monitor the UK's progress in this field since modelling in all its aspects is a key recommendation in this report. Other activities have included reports and meetings run by the Institute of Materials and a discussion led by Prof Alan Windle on the concept of a "Virtual Material" at the July 2000 "Consulting the Community" day. This was based on the outcomes of the Foresight Challenge award held by Professor Windle at the University of Cambridge.

The panel has also been actively involved with DTI and NPL in discussing the work that should be undertaken on methods for obtaining data for modelling of processes. The response of EPSRC in sponsoring the cross programme initiative "Materials and Processes for Engineering Applications" is also acknowledged.

Materials for sensors. This has received no focused attention to date. The panel has now set up a group to look at this further. It will be expected to report in 2001. An attempt has been made to engage the magnetics industry without substantial success at present.

New generation of biomaterials. This has received extensive attention since the first report was published. A review on the research base was published by the Royal Academy of Engineering ("A Review of the UK Research Base in Biomaterials", August 1998, ISBN 871634 58 X). This recommended the creation of two centres, one in tissue engineering the second in urology. The first of these has been taken forward by a joint research council's initiative to set up two groups for this purpose. The nature of the UK industry was assessed in a DTI report and resulted in the "Building up Biomaterials" initiative. They have subsequently set up a strategy group who is also responsible for undertaking a Foresight Consultation. The main outputs from this are listed in section 5. In addition Professor Bonfield has led an ITS mission to Japan, which reported back in early 1999, and he has chaired an IOM division on biomaterials who have a Foresight remit.

■ **Processing Technologies.** The Foresight report "Sensing the Future" addressed the need for robust monitoring of processes. EPSRC have supported the IMMPETUS initiative on metal processing based at Sheffield University including a number of key industrial partners. The MaPEA programme is also giving grants in this area.

■ **Light weight materials.** A Foresight report on materials for the aerospace industry has been published by the IOM and ongoing meetings have taken place. A number of DARPS in this field have been created and there is considerable ongoing research supported by a number of organisations. The IOM have created a Light Metals Division and there are now ongoing Foresight activities in aluminium, magnesium and titanium. The panel created a packaging task force who have published a consultation document (available on the Foresight website (www.foresight.gov.uk)) and this will continue to be an area for attention. ALFED have recently published a comprehensive survey on the future needs for aluminium in the construction and transport sectors. A short summary of the main findings is given in section 5. There are also ongoing Foresight activities involving plastics and composites organised by the IOM.

■ **High Temperature Materials.** The needs of the Aerospace and Defence Industries were initially published and discussed in "Aerospace Materials and Structures: The Report of the Defence and Aerospace Foresight Panel Technology Working Party" and this aspect is now being covered by the new Defence, Aerospace and Systems panel.

Likewise there has been extensive activity in the field of materials for power generation under a large-scale survey led by Dr. Nick Otter of Alstom. ("Foresight Research, Development and Demonstration Priorities for Gas Turbine and Advanced Combined Cycle Technology" - available on the Foresight website)

■ **Processing of High Temperature Superconductors.** There has been no focused activity relating to this topic.

In addition to these key recommendations there were several other points raised in the first report for which some actions have or are taking place.

■ A town meeting was held to discuss magnetic information storage. No concrete actions resulted from this.

■ TWI is undertaking a Foresight analysis on joining techniques. A report is awaited

■ A report was sponsored by DTI/OST on surface engineering and is available on the Foresight website (www.foresight.gov.uk) for consultation. The IOM Surface Engineering Division has also produced some recommendations for specific applications and a summary is available in section 5.

■ The role of the Institute of Materials in sponsoring Foresight. The IOM in addition to the Institute of Physics (IOP) and Royal Society of Chemistry (RCS) have run their own Foresight programmes in this round. Much of this has been relevant to the work of the Materials Panel. The reports on these activities are available from the institutions concerned. Of particular note is the assessment of the future of Materials Chemistry produced by the RCS.

■ Engaging Industry. A considerable number of meetings have been attended by the panel to engage trade groups, individual companies and top executives. A one-day meeting was held in early 1998 attended by 25 relevant Trade Associations where a booklet entitled "Materials Advantage" was launched describing case studies on successful materials sector Foresight activities. This was supported by several speakers outlining the lessons they had learnt by such exercises. A number of Trade Associations started their own analyses as a result of this. One high level dinner has been held to obtain constructive feedback and to ensure ownership of Materials Foresight by key companies. This will be an ongoing exercise.

■ There has been extensive debate about the need for large centres of excellence in materials and the restructuring of degree courses. This is still ongoing. The impact of the survey by the Engineering Council on the profession, education and training is awaited and is expected to have significant repercussions for how materials are taught in universities. This is in addition to how universities themselves will develop over the next ten years. The panel has been actively involved in these discussions and will continue to monitor progress. It is believed that there is considerable need for identifiable degree programmes in materials science and engineering in addition to identifiable research centres. It is acknowledged that these may be significantly different in focus as the UK moves away from a supply driven materials base to one dominated by end user demands.

4 | What's different from last time? - Modus Operandi of the Panel

In the first round the panel was quite large and tried to be as representative as possible of the various materials sectors. As such, the burden of activity fell on relatively few and while the experience of the larger panel was useful, it was clear that a smaller, more involved panel was required in the second round if the objective of engaging the community was to be fulfilled. Thus the panel in the second round was not selected on the basis of representation, but rather on the ability to take a wide overview and to be actively involved at the highest level. Representatives from the DTI, Institute of Materials and the EPSRC were also members who provided valuable conduits within the various organisations for feedback and dissemination. It is interesting to note that there has only been one change of membership in the life of the second panel to date.

It is now the intention to recruit further members of the panel who will bring fresh insights and gradually replace many of the existing team who deserve a rest from their labours.

As stated in the introduction, the panel has operated by trying to encourage sector groupings in existing areas to undertake their own exercise and to then provide feedback to the panel. This was much more labour intensive for the panel than originally conceived. Where possible, funding for such an activity has been obtained from the relevant parts of government. At the time of writing this report, there are over 20 such groups who have either reported or are in progress.

Individual panel members have been responsible for overseeing these sector activities in addition to setting up new groups such as in the area of nanotechnology, packaging, modelling etc. Reports on all these are available via the Foresight website (www.foresight.gov.uk).

In addition, the panel have been involved in Young Foresight, International and Regional Foresight. However their main focus has been on the national perspective although even this is a limitation since the users and suppliers of materials in the UK are not bound by political boundaries within the UK and most see themselves as global players. The links with the Thematic Panels have been especially good and there are several ongoing initiatives that have resulted from this.

A justifiable criticism of this way of working is that the sector organisations do not see the wider picture. This is true to some extent and the panel has tried to counter this by providing the balance. However it has been found that too much "over the horizon" thinking leads to a lack of ownership with the wider community. While it is fun to think the impossible, it does not normally lead to coherent actions. The panel has tried as much as possible to inject reality checks into the self-contemplation of sector groups. Questions are posed that can jolt the most introverted analyst into some reaction. For example: "Are architects necessary in a knowledge based society: What will happen if the climate change levy is doubled; How can the UK respond to the fact that the number of qualified engineers will be half the present number in ten years time..." and so on.

5 A brief glimpse at ongoing Foresight activity

It has always been the aim of the panel to engage relevant communities in the Foresight Process. Each group interpret things in different ways and expect different outputs. While the panel has produced guidelines, we have been keen to ensure ownership by the relevant community for what they do rather than impose restraints. There are, for example, large differences in time horizons with those that are more focused on current industries having the shortest time horizon. In the short features that follow we present several examples of ongoing activity. They have been written by different people in different styles and the Panel does not necessarily endorse the views they contain. In some cases we have extracted key points from much larger reports. This is a selection designed to give some flavour to what is a much larger exercise. We received more information than could be included. Most of the activities are ongoing and at this point the panel would like to offer their grateful thanks to all those that have taken part. If you should wish to know the details then please refer to the individual websites or organisations. More importantly, should your sector wish to become involved in undertaking a Foresight exercise, please contact the Materials Foresight Secretariat as soon as possible.

Ceramics

INTRODUCTION

A sector based consultative process called CERAMICS: TECHNOLOGY FORESIGHT 2000 has been carried out by CERAM Research Ltd, Stoke-on-Trent. It is a bottom-up collection of views and their analysis aimed at identifying business drivers, issues and technologies/innovations relevant to the next ten years.

CERAM has divided the market into three major sectors:-

- Building Technology
- Refractories and Industrial Ceramics
- Whitewares

The drivers, the responses and the benchmarking are naturally different between the sectors. Full details are available in the report which is available on the Foresight website (www.foresight.gov.uk) The diagrams here are constructed from this report.

BUILDING TECHNOLOGY SECTOR

Business Drivers	Issues	Technologies/Innovations
Market Expansion and Market Defence Through More Efficient Construction	Inefficiency, waste, speed of construction	HOBMAN II type projects New jointing systems, thin bed mortars, adhesives
	Shortage of skilled bricklayers	Dry and prefabricated construction systems
	Impact of wet trades on site	Training and education, better IT tools for design, detailing, specification and tracking De-skilling construction
Cost (and Tax) Reduction Through More Efficient Manufacturing	Quality improvement, colour, size, consistency	Automation, robotics, inspection systems
	Pollution control Raw and secondary raw materials	Faster drying and firing Additives, reassessment of secondary materials
		Practical, harmonised product standards Environmental standards
		Integrated energy management
Market Expansion by Addressing Needs for More Thermally Efficient Buildings	Environmental performance of clay bricks	New wall construction concepts, internal walling
	Customer choice	Product size and shape
	Products standards	Life cycle analysis
Environmental Policies and Concerns	Cradle-to-grave environmental performance	Improved monitoring linked to IT and audit tools

Key: = On Track = Some Progress = No Progress

Interestingly CERAM makes the following conclusions on progress in response to drivers in building technology:-

“One would have to conclude that in this area the sector has reacted to protect existing markets. The areas where less progress has been made are broadly in the education and training field aimed at making design specifications and the use of the sector's products easier and which are more related to proactive moves to not only maintain position but to expand new markets.”

WHITEWARES SECTOR

Business Driver	Issues	
Low Price Competition	Improvement of yields and productivity to reduce the manufacturing cost base	<p>Materials:</p> <ul style="list-style-type: none"> ■ Better specification, testing and control ■ Pre-processed materials <p>Process:</p> <ul style="list-style-type: none"> ■ Automation plus flexibility, fewer steps, better linking ■ Automated firing, less firing steps ■ Improved glaze application and decoration flexibility ■ Better control of processes <p>Operations:</p> <ul style="list-style-type: none"> ■ Improved production planning, layout, scheduling ■ Inspection and feedback ■ Lean manufacturing techniques
Retail/Customer Demands for a Faster Response	Agile manufacturing to permit the combination of product variety with faster response	<p>Process:</p> <ul style="list-style-type: none"> ■ Agile manufacturing, rapid changeover, small batch capability ■ Low cost, short run, custom decoration ■ Once fired decoration <p>Operations:</p> <ul style="list-style-type: none"> ■ Integration of manufacturing systems, cells ■ Supply chain logistics ■ Automated processes including inspection and handles
Changing Customer Tastes/Lifestyles	Accelerated introduction of new products	<p>Process:</p> <ul style="list-style-type: none"> ■ Rapid prototyping ■ CAD and rapid transfer to forming and decoration processes ■ Capability for novel shapes and finishes ■ Identification of changing tastes <p>Operations:</p> <ul style="list-style-type: none"> ■ Integrated design and manufacturing
Customer Satisfaction	Quality and safety in service	<p>Materials:</p> <ul style="list-style-type: none"> ■ Remove perceived hazardous substances <p>Process:</p> <ul style="list-style-type: none"> ■ Product labelling and traceability ■ Automatic sizing and selection ■ Improved "in use" properties <p>Operations:</p> <ul style="list-style-type: none"> ■ Supply/distribution logistics ■ Defect free products/orders; QA systems
Environmental Legislation/Concern	Product and pollution liabilities. Green image	<p>Materials:</p> <ul style="list-style-type: none"> ■ Remove/reduce hazardous substances <p>Process:</p> <ul style="list-style-type: none"> ■ Waste reduction and recycling ■ Energy efficiency and management ■ Packaging developments <p>Operations:</p> <ul style="list-style-type: none"> ■ Comparative life cycle analyses

REFRACTORIES & INDUSTRIAL CERAMICS TECHNOLOGY

Business Drivers	Issues	Technology & Innovation Requirements
Market Competitiveness & Company Profitability	Improve manufacturing efficiency and product innovation	<p>Materials:</p> <ul style="list-style-type: none"> ■ Update/confirmation of reported properties ■ Innovation for process efficiency <p>Process:</p> <ul style="list-style-type: none"> ■ New/modified and simpler processes ■ Automation in handling <p>Product:</p> <ul style="list-style-type: none"> ■ Industry involvement in international standards ■ Faster installation/commissioning (refractories) ■ Reliable databases and improved performance (industrial) ■ Predictive performance models
Customer Demands for Value in Use	<p>Improved consistency - tolerance and performance of products</p> <p>New and improved products through innovation</p>	<p>Materials:</p> <ul style="list-style-type: none"> ■ Better specification and control <p>Process:</p> <ul style="list-style-type: none"> ■ Better control on variables ■ On-line NDT <p>Operations:</p> <ul style="list-style-type: none"> ■ QA support, traceability <p>Refractories:</p> <ul style="list-style-type: none"> ■ Surface interactivity, matrix and bonding systems, structures, thermomechanical properties
Environmental Legislation/Concerns	Product and pollution liabilities. Workplace environment	<p>Materials:</p> <ul style="list-style-type: none"> ■ Replace organic systems with aqueous ■ Alternatives to chrome (refractories) ■ Standardised tests for crystalline silica ■ New binder systems <p>Process:</p> <ul style="list-style-type: none"> ■ Reduce vibration/noise ■ Waste reduction and recycling including improved sorting ■ Energy efficiency or novelty in drying and sintering

This excellent work by CERAM shows an industry needing to be pro-active about longer term issues. Investment in training and control of environmental impact could well create competitive advantage for those players willing to take the opportunity.

Advanced Ceramics

The Advanced Ceramics Task Force overviews high-performance **functional and structural ceramics** designed and fabricated for **high-tech applications**. Its work focuses on:

- Electrical ceramics
- Structural ceramics
- Bioceramics
- Chemical functions
- Ceramic composites
- Ceramic coatings
- Special glasses

Provisional conclusions include:

For **electrical ceramics**, it is recommended that there is a need to stem the flow of materials system developments away from the UK. Industry should be encouraged to innovate with imported materials systems; future strategic supplies need to be assured. Academic effort needs to achieve critical mass; networking should be encouraged; improved co-ordination and (virtual?) centres of excellence should help.

Structural ceramics have well-defined niche markets, but future efforts should be devoted to improved cost-effectiveness. Industry should focus on cost reduction by cheaper processing and alternative raw materials. Academic research is also fragmentary but internationally recognised; improved toughness, high-performance coatings and intelligent use of novel chemical processes are research priorities.

Ceramics for chemical applications include catalysts, laboratory ware, valve plates, seals, bearings, electrodes, filters, and membranes with controlled porosity. The market is steadily increasing, and industry must focus on finer-scale design of chemical and microstructural features. Future requirements/developing fields include: use of more sophisticated chemical routes; nanofabrication for controlled porosity and foams.

Biomaterials

Biomaterials are essential constituents of many medical devices that are used in direct contact with the body and the clinical performance of these devices is often related to the biomaterial properties. Biomaterials and their associated medical devices are an important future technology for the UK; both in terms of their health care capabilities and the opportunities they present for wealth creation.

Technologies that are emerging from the science base present new opportunities for biomaterial based therapies. Indeed, the future therapeutic applications of biomaterials may depart quite radically from the use of biomaterials in the past. Specifically, future biomaterials are expected to modulate physiological functions and actively encourage repair and clinical recovery.

Furthermore, the demand for biomaterial based therapies is expected to increase through demographic changes that will lead to an increasingly aged population, both nationally and globally. Improved medical devices to restore or replace the function of deteriorating body parts are necessary to meet expectations for a continuation of a 'normal' and active lifestyle through into old age. Biomaterials will be the basis of clinical treatments that will address the major tissue degenerative diseases.

Biomaterial development is essentially a multi-disciplinary activity. Progress depends on the combining of clinical and academic expertise across a broad spectrum of disciplines, together with industrial contributions that are essential to provide patient access to new biomaterial devices. It is essential, therefore, that a Foresight approach is adopted to illuminate future opportunities for biomaterials. A consultation process undertaken with the UK biomaterial community was therefore undertaken on the Materials Panel's behalf with contributions received from academic, clinical and industrial members of the biomaterials community.

The findings from this consultation process are reported below, condensed into four 'Bullet Points' that represent the key conclusions of the exercise

Over the next 20 years: -

Biomaterials will be used to modulate and restore or replace the normal physiological function of a wide range of tissues and organs. In this way the quality and longevity of tissue repair and disease treatment will be optimised. This approach will include: -

- Biomaterials in combination with cells to reconstruct diseased body parts (tissue engineering). These will become increasingly customised for the patient.
- Biomaterials that degrade in a controlled fashion to be replaced by biological tissues.
- Biomaterials that encapsulate cells and allow these to perform their physiological function.
- Biomaterials with specific surface properties or coatings that will stimulate a specific tissue response.
- Regeneration of neural tissues and other uses of biomaterials for guided tissue regeneration.

Intelligent imaging, robotics and, in particular, nano-technology developments will have key implications for the development of future biomaterials in the following areas: -

- Surface modification of medical devices to enhance their biological interfaces.
- Improved accuracy in the placement of biomaterial devices.
- Biomaterials that can be secured to anatomic structures using less invasive surgical procedures.
- Micro-machines and 'nanobots' to facilitate the increasing use of minimally invasive surgical procedures.

- External applied surgery will require biomaterial properties to be controlled remotely, perhaps by self-assembly or development 'in-situ'.

- Nano-pumps for drug release controlled by external stimuli.

- Smart implants that react to implanted biosensors.

Implanted biomaterials will be used to control the delivery of some drugs and biologics.

Factors include: -

- The cost of the drug treatment will determine the biomaterials use.

- Possibilities of slow drug release over extended timescales.

- Biomaterials as vectors to control infections and haemorrhage.

- Trans-dermal and sub-dermal controlled drug delivery.

- Pharmaceuticals that enhance material biocompatibility and clinical performance.

- Biomaterials that mimic drug responses without adverse side effects.

Biomaterial based therapies will be subject to changing patterns of healthcare delivery, increased regulatory constraints, extensive medical device tracking and more sophisticated clinical performance measures. Patient recipients will be more involved in the selection of their medical devices, although device cost will continue to be a limiting factor. These will lead to: -

- Including patient information and education as part of the whole medical device 'package'.

- Sensational reporting may well create false expectations.

- Increased need for validated simulation tools to understand biomaterial device clinical efficacy and failure.

- Cure rather than a treatment will be sought and this will drive the development of biomaterial technology, for example, cell encapsulation techniques as a one-stop gene therapy modality.

- Shorter hospital stay will drive the application of novel biomaterials.

- Non- and minimally invasive diagnostic methods and biomaterial device monitoring will bring about the earlier use of more conservative biomaterial treatments.

- Direct GP referral to more specialist medical centres.

Composites

The UK polymer composites industry is a somewhat fragmented sector that spans from low technology GRP laminators through to sophisticated aerospace fabrication.

A consequence is that there is no single body through which the industry can speak or be represented. In response to this, a working group initiated by the Institute of Materials Composites Division is planning a consultation exercise to develop scenarios that the whole sector is likely to face over the next ten to fifteen years. Already the key issues to emerge are those of sustainability (especially driven by tightening legislation) and manufacture (aiming to improve the cost / performance balance).

As importantly though, changing requirements and increasing awareness of industry together with a review of raw material supply may start to provide the "market pull".

Sustainability

Environmental legislation (such as landfill tax, climate change levy, regulations about effluents and VOC emissions and the drive for recycling) increasingly will produce operational and cost problems for the composites industry. The issues start right from the production of the basic materials (the polymers and reinforcements) and carry through the composite manufacture to the final end service need to recycle. As far back as the early 1970's Esso were forced to discontinue the production of the preferred epoxy resin for the aerospace industry because of environmental impact in New Jersey. The cost to the industry was great because of the huge investment needed to research and re-qualify a new system for existing applications.

Business opportunities are emerging because of the need for change. For example, open mould techniques for large components are being superseded by closed mould processes, e.g. RTM, to reduce workplace emissions. The holy grail however remains the creation of a system which allows for easy recycling, a pre-requisite for realising some of the huge potential for lightweight structures in the land transport market.

Semiconductor and Opto-electronic Materials

ANALYSIS OF MATERIAL CAPABILITY

The UK has had a long history of developing electronic materials and understanding their properties, although much of this expertise and understanding was founded and still resides mostly in universities and government funded laboratories. Just as an example, much of the understanding of bulk GaAs crystal properties and growth was developed at RSRE Malvern, which provided a comprehensive knowledge base and foundation for present day capabilities.

The analysis of electronic materials is best split into two sections, relating to the technology maturity in terms of market penetration and age:

■ Silicon & SiGe

■ GaAs and Compound Semiconductor materials

SILICON:

Although there is significant investment within the UK (particularly in Scotland in the so-called Silicon-Glen) for microelectronic fabrication and circuit design, the level of activity for research and development, particularly for materials, is weak. This is a consequence of a) the low levels of investment in R&D compared with overseas and b) the level maturity of silicon technology compared with other semiconductor materials. The industrial base within the UK focuses on fabrication and design of Silicon microelectronics. There is no industry developing and supplying the base material. The level of industrialisation also means that the scale of investment in state of the art processing equipment is such that no UK academic or government laboratory can have or justify a complete suite of the most up date equipment

Device processing within UK academia, which allows the opportunity for device research and design, is at least 6 generations out of date compared to commercially available processes (2_μm rather than 0.18_μm commercially available).

GaAs & OTHER MICROWAVE AND OPTO-ELECTRONIC SEMICONDUCTOR MATERIALS:

The industrialisation and application of GaAs and other Compound Semiconductors is relatively immature compared with silicon and as such both UK academic-research and industry has significant interest and activity at all levels from supply of the raw material to device, circuit design and fabrication. In addition, the current growth in communication networks is fed by the opto-electronic components that allow routing and switching within optical fibre networks. The UK has a strong position in this area thanks to past investment by leading companies and the market has also led to new opportunities and expansions within the UK.

ELECTRO-OPTIC AND DISPLAY MATERIALS:

Although Electro-optic and display materials mostly fall outside the remit of semiconductors, it is important to realise that the new markets in communications and media technologies depend on these types of materials. Electro-optic materials (such as Lithium Niobate) and display materials, such as novel liquid crystals like Zenithal Bistable (ZBD) materials and organic PVVs exploited by Cambridge Display Technologies are all important for future communication systems. The UK has significant expertise in these critical technologies which should not be overlooked.

Analysis of Opportunities for the UK

There are several opportunities for new development of Si based materials. The first is the use of Si as an 'engineering' material to fabricate micro-machines and components for fibre-optic systems. Micro-ElectroMechanical Systems (MEMS) could have a major impact in many technologies from vibration sensors in washing machines to micro-mirrors in large projection display systems. The technology is immature at present, with the main applications focussed on the air-bag sensor and ink-jet printer markets. The basic processing is based on existing Si techniques but since the device-scale is larger than state-of-the-art microelectronic technologies the size of investment for significant facilities is fairly modest and potentially very competitive. The UK could have a major impact in this technology area.

Although Si microelectronics is a mature industry, the UK has significant expertise on Si and dielectric deposition and process control. Whilst there is little opportunity to develop novel device architectures which the microelectronics industry will take up, there is an opportunity to take advantage of deposition and process control knowledge by collaborating in with major European activities in microelectronic research and so achieving world-class level at a realistic investment.

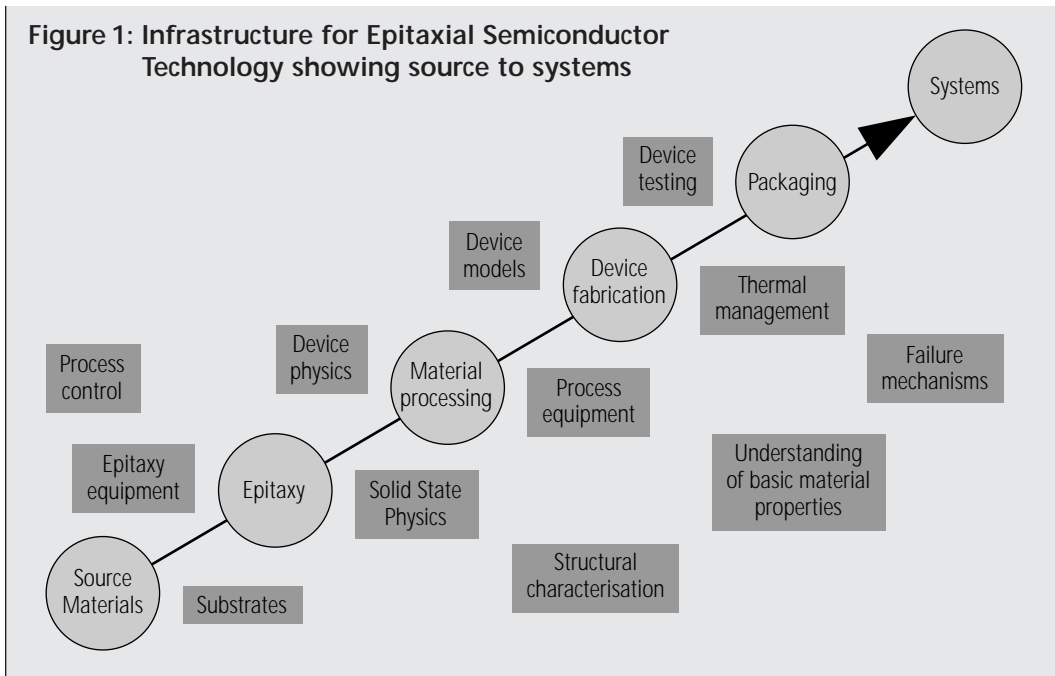
Compound Semiconductor technology is fairly integrated within the UK, with activities at all levels. Figure 1 shows the typical infrastructure required for the development and production of semiconductor epitaxial layers. An example might be GaN based applications, which is a new material with considerable promise. The UK has activity and expertise at all levels. Such a situation provides an opportunity to strengthen and maintain this capability, so that the UK maintains a global position in the III-V and Compound Semiconductor materials markets.

Unlike Si, compound semiconductor materials technologies have relatively low integration levels, this is partly a consequence that current integration is costly. Thus there is an opportunity for cost-effective ways of increase system integration/functionality in III-V semiconductors for example by combining both optical and microwave electronic components. Such integration is likely to require enhanced or new material deposition and processes (for example: selective epitaxy techniques to combine both lasers and microwave devices).

RECOMMENDATIONS

Opportunities for work on Si based materials are limited as a consequence of the scale of investment needed for all aspects of a full vertically integrated research programme. There is no justification for purely or partly government funded state-of-the-art Si processing lines for either research or training within the UK. Microelectronic factories tend to train operators and technicians at their own sites or at equipment manufacturing training sites. UK training should be limited to 'good practice techniques', which can adequately be maintained on existing UK university facilities.

Figure 1: Infrastructure for Epitaxial Semiconductor Technology showing source to systems



The UK should concentrate on key elements of the Si material processing and process control technology, where an impact is likely to be achieved and only where collaborative links to European programmes and processing facilities (such as IMEC or LETI) allow an integrated and coherent programme.

This approach will benefit UK investment by utilising the significant gearing from European programmes and will allow the UK to be world class in key areas. However, such an approach will require the lead from EPSRC and DTI on funding allocation, to engender this change in emphasis and agreed arrangements with the partnering laboratories within Europe.

In addition, there is scope for developing communication systems and opto-electronic applications on Si based technology. It is recommended such innovative system-related research is funded through focused calls from the research councils and industry, rather than in responsive mode from researchers, which can tend to lead to a more fragmented infrastructure. Such work should be focused at specific centres to the gain highest impact for minimal overhead or failing that, 'virtual centres' to gain interdisciplinary advantages. The nature of the targeted work should allow easy independent assessment of progress and value, compared with existing Si based work, which has ill defined objectives. Continued work on speculative or inventive applications of Si based materials should continue only in responsive mode funding.

Specific areas where Si based materials could have major impact and focused:

- Si as an engineering material for MEMS
- Si as a material for opto-electronic & RF communication systems (not devices), e.g. photonic band-structures and waveguide technologies
- Si material process and metrology modules linked to key EU centres

GaAs AND OTHER COMPOUND SEMICONDUCTORS

As a contrast to Si technology, GaAs and other opto-electronic technologies have a fairly integrated structure or more extended coverage within the UK.

To enable continued growth, specifically in the higher parts of the technology 'food-chain' (see figure 1), the UK requires device and circuit designers to have low volume access to material and processes, so that novel devices, circuit and systems can be developed. This requires basic infrastructure and funds for underpinning capability; it is recommended at least two centres are established (not necessarily at Universities) to enable this to happen in an open, competed and effective way. (However, it should be noted that the current way of funding in 'responsive' mode funding by DTI and EPSRC tends to go against underpinning work in favour of novelty, thus the current approach threatens the development of capability and indeed threatens the continued support of existing capability). This should enable UK to maintain a team player status and allow existing collaborative DTI LINK & EPSRC programmes to flourish. These centres and funding for them should not detract from the current and very successful approaches to funding research and development in opto-electronics and photonics technologies through responsive modes, particularly the LINK programmes. It should aim to strengthen such approaches by providing a basic infrastructure to enable higher level growth and development.

Additional effort should be placed on increasing key functionality in high-speed communication components and systems. Such functionality might come from increasing the integration level of Compound Semiconductors by combining both electronic (microwave) and opto-electronic components but this has to be done in a cost-effective way. Such integration might come from new epitaxial and processing techniques and if these proved cost-effective, UK industry would obtain good competitive edges in component and system supply.

Light Metals

Industry structure: Consideration of light metals is concentrated on aluminium as although magnesium has important and growing applications, its main use is likely to remain as an alloying element in aluminium alloys for many years to come.

Primary smelting of aluminium is backed up by a high level of secondary melting and recycling. The relative proportions of these three sources in the UK has changed significantly in the UK over the last ten years as illustrated in the chart below.

The increasing importance of recycling is readily seen and this is particularly significant from both an ecological and cost standpoint because primary aluminium is energy intensive and secondary melting and recycling only require 5% of that energy. Aluminium can be recycled many times with no loss of properties, provided the different alloys are separated and the proportions recovered vary from 30% in packaging up to 95% in automotive scrap. Although diminishing returns limit the potential savings, significant further increases in recycling of packaging can be expected as the UK catches up with the 65% achieved in the USA and Australia and the optimum could be over 80%.

Aluminium market sectors

Foil and sheet for packaging and can production is overwhelmingly the most important application for aluminium on a tonnage basis.

Transport is a major sector with large growth opportunities. The weight of aluminium per car has increased by 35% between 1991 and 1999. Although automotive applications dominate the transport sector in tonnage terms, aerospace is important in terms of added value and aluminium is increasingly used in ships and railway vehicles.

Construction is the other major business sector for aluminium and the new Media Centre at Lords Cricket Ground is a brilliant example of the use of aluminium.



KEY REQUIREMENTS FOR INCREASED USE OF ALUMINIUM

General: Although aluminium has generic strengths in terms of low weight, formability, corrosion resistance and recyclability, the significance of these factors varies from market to market as do the disadvantages of high prime cost, difficulty of joining and uncertain fatigue performance.

Aluminium will continue to rely on the Hall-Heroult cell over the next 20 years and although there has already been a 65% reduction in emissions of global warming gases in primary production over the last 10 years, smaller further improvements are possible. The industry as a whole is committed to improving energy efficiency by 20% over the next 20 years.

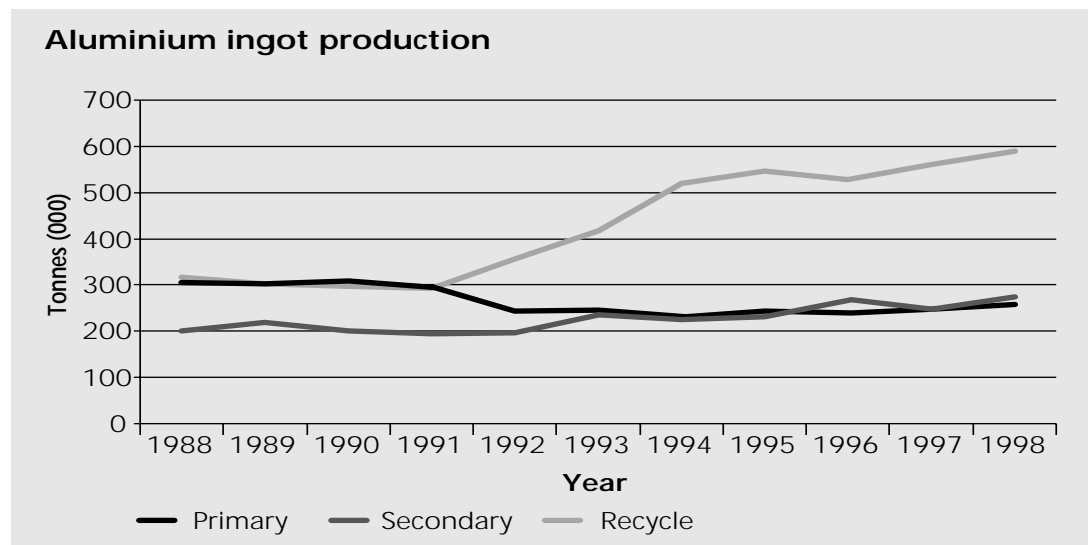
These improvements in efficiency need to be complemented by promoting aluminium as environmentally friendly through adopting a life cycle approach based on its recyclability.

Packaging: Aluminium's strengths are heat and corrosion resistance. In the USA and Australia aluminium beverage cans have driven out steel because of environmental advantages. PET is a major threat if economic recycling is achieved and aluminium needs to combat this with further improvements in can design (e.g. resealable cans). Opportunities for growth come from extending this success to food containers and from increasing home use due to the trend away from microwave cooking to chilled food cooked in the oven. Cost reductions are achievable if continuous casting is extended to 5000 series alloys.

Transport: Here, weight saving is the major driving force for increased aluminium use. Although weight saving improves fuel efficiency, in the automotive sector the saving is often utilised to enhance performance or to accommodate 'luxury add-ons' such as air-conditioning. The major growth opportunity for aluminium in automobiles is in extending use in bodywork; barriers to be overcome are the need for improved joining techniques, impact resistance and reparability. Research into alloy development, testing (especially fatigue) and design is needed to address these issues; aluminium honeycomb structures and foams have considerable potential for impact resistance.

In aerospace, 2000 and 7000 series aluminium alloys are likely to remain the major materials for airframe construction but continual alloy development is required to provide an even better mix of properties. Designs for sub-sonic aircraft with capacities of up to 1000 passengers will drive these developments rather than Concorde2. Extensive use of more radical approaches such as aluminium lithium alloys and MMCs is unlikely in the short to medium term in view of the long lead times in aerospace.

Construction: The sustainability of aluminium is a major advantage and aluminium has a good track record in enabling the re-use and refurbishment of buildings. Existing alloys meet present property demands but the industry needs to educate architects and designers in the advantages of aluminium. The concept of setting up UK centres of 'Aluminium in Building' at selected Universities is being examined; these would provide a focus for development as well as a source of information.



Key initiatives

ACTIONS	MAIN BENEFIT AREAS				
	Cost	Environment Energy	Recycle	Quality	Market
Education & Promotional					
Disseminate educational material on aluminium to schools, Universities and end users					Y
Expand training schemes such as NVQ	Y			Y	
Use promotional literature from other parts of the world					Y
Learn from greater per capita use of aluminium elsewhere					Y
Ensure aluminium industry well represented in areas of standardisation and legislation	Y				Y
Extend property data available for modelling aluminium Behaviour in use				Y	Y
Develop an aluminium design centre with facilities for design, Testing and construction for specific uses				Y	Y
Promote recyclability of aluminium and its 95% energy saving		Y	Y		Y
Economic					
Price stability for long term customers	Y				Y
Exploit advantages of aluminium in refurbishing old buildings			Y		Y
Exploit opportunity for Al foil containers arising from trend away from microwave to conventional ovens					Y
Exploit aluminium potential in food cans					Y
Meet need for gas containers if cars move to bottled gas fuel					Y
Energy					
Adopt a full Life Cycle approach	Y	Y			Y
Continue to reduce global warming gas emissions	Y	Y			
Improve Energy efficiency of Hall-Heroult cell	Y	Y			
Cut costs and reduce energy use by extending continuous casting development to all alloys	Y	Y			
Technical					
Research and development on fabrication, joining & finishing				Y	Y
Meet requirements of very large passenger aircraft				Y	Y
Counter threat from PET with new can designs (e.g. resealable)					Y
Improve technology for scrap sorting into alloy types	Y		Y	Y	
Improve recycle rates; especially in packaging Emphasise producer responsibility			Y		

Predictive modelling

Materials Modelling includes familiar tools, like FE/FD or CFD, which are already part of engineering practice. However Predictive Materials modelling goes much further. State-of-the-art electronic structure calculations can lead to cements with the right setting times, or to the best choices of piezoelectric transducers. Atomistic studies can identify the right catalyst system, or the behaviour of nuclear fuels in extreme conditions. The quantitative understanding of structure at the mesoscale and how these structures are created can improve polymers, ice cream and thermal barrier coatings. Quantitative thermodynamic, kinetic and statistical modelling enables alloys exceptional performance. The UK has been a pioneer in these fields. However the speed with which the technology is developing, coupled with the restructuring of industry often at the expense of its large R&D functions, prompted the Materials Panel to carry out a review of the UK's current and future capabilities in predictive materials modelling. The results of this work are contained in a report available on the Foresight website. But in summary the review concluded:

Expansion of courses, looking at and beyond new graduates, mature students and those from all national backgrounds should be welcomed, without restrictive grant rules. "Defining the problem" issues are even more important than training in software use. Since trained students are valuable in many roles in industry, numbers should not be limited by perceived needs for specialists alone.

Software industries are crucial role in transforming science-based codes into products for non-specialist users. Funding software development is very difficult in the UK. This must change for scientific software industries to flourish. Development should occur in whichever sector (industry, academia, national lab) is best equipped. International collaborations should be welcome. Software still needs credibility: users do not trust electronic structure or mesostructure calculations yet, and working assumptions are not intuitive. International competition drives enhancement of hardware. Public-funded, state-of-the-art, hardware should be available to industrial users under reasonable conditions.

Management Few managers in industry recognise the opportunities offered by predictive modelling. Active groups in industry are often too small and too transient to be effective. Achievements of modelling are easily underestimated, especially through filtering out flawed proposals. Ways must be found for activities with longer timescales (say 5 years); such perspectives are more easily met in national laboratories or universities.

Recommendations:

EDUCATION

Materials modelling courses should be expanded in size and variety, and cater for students who might have careers outside materials modelling. There should be minimal restrictions on the eligibility of students, provided the quality and identified need are strong.

MANAGEMENT

Given the important role of national laboratories in the past (especially Daresbury, NPL and Harwell), and their continuing major role in the USA, we recommend that such laboratories be encouraged to work with the academic and industrial sectors to provide web-based information on the widely-spread areas of materials modelling, together with some level of professional guidance and support. One specific aim would be to ensure that non-confidential expertise remained available.

Investment in education will help, as would some of the existing schemes, like Teaching Company schemes. Organisations like EIRMA (European Industrial Research Managers Association) make serious efforts to improve management, but not all the UK firms that might benefit actually subscribe.

Because there are probably wider opportunities for predictive modelling than are perceived within the industry sector. Information on case studies and good practice needs to be continuous and given wider publicity. Publicity need not be delayed until economic payback has been achieved, since developments are very fast in this field.

Modelling/software is already a commercial enterprise, and one in which the UK has made important contributions. The follow-up from a research code (which might start in industry or academia) to (say) a well-packaged PC-based product for a non-expert modeller is challenging. It has been suggested that an obstacle to take-up of these tools in UK industry was the relative lack of stable modelling teams of critical size. There is no simple solution to this problem, however those with closer knowledge of venture capital and its many variants might examine possibilities for modest grants or loans to ease the creation of user-friendly code, and especially for validated software appropriate for use on PCs in SMEs.

HARDWARE

It is always possible to use more computer speed, better displays, and so on. The time for the latest science to be adopted in practical modelling is similar to the time for the latest in hardware to become the norm. The situation should be reviewed regularly.

Nothing should be done to create obstacles to exploiting new opportunities, like inappropriate depreciation rules, or refusing industry access to large computers in the academic sector (because informed and active scientists and engineers in industry are the most likely both to take up academic ideas and personally to champion industrial support of academic projects).

SOFTWARE

Where appropriate, benchmarking of codes and of working assumptions should be encouraged. Modest support should be given to informal international networks offering help and experience for the best-known codes, especially as a means to address credibility of results issues.

■ Since good software is still being initiated in industry, EPSRC and the academic community should be encouraged to support development of such industry-led software.

■ The proper documentation of software, especially that written by research students is important. Know-how about codes is passed on largely by word-of-mouth, and is lost when a code is not used for a period. If there is to be proper documentation, students must be funded for longer (4 years might be appropriate) without their Department being penalised for taking this longer completion time. EPSRC (1999) has agreements with universities that primary data (apparently including files of results from codes) be archived, but does not require the code to be documented.

LONG TERM FUNDING OF PROJECTS

■ Although we understand there is no formal EPSRC limit, it seems much harder in the UK to fund projects for more than three years. Even for the extremely successful polymer modelling activity, which followed from the previous Materials Foresight report, it is clear that more than the basic three years was needed to achieve proper industrialisation. As noted, three years also makes the proper documentation of code written by graduate students very difficult. Our belief is that funding of some large, long-term (5 years or more) projects will be needed if the potential of predictive modelling is to be achieved.

Nanotechnology

The promise of nanotechnology: "So powerful that it will allow desktop manufacturing.... So portable that everyone can reap its benefits.... So radical that it will change our economic and political systems.... So imminent that most of us will see its impact in our lifetimes."

Kai Wu, Cornell University.

The march towards miniaturisation carries on at a relentless pace. The promise that one can obtain more for less, produce smaller, lighter, cheaper and faster devices with greater functionality while using less raw materials and consuming less energy is beginning to be realised. This promise derives from the world of nano technology and nano science. It's a world which also promises better electronics, computers, communications, improved medical diagnostics and treatments, better environmental sensors and less pollution.

The nano world is defined as a technology in which " dimensions and tolerances in the range 100nm(0.1microns) to 0.1 nm play a critical role". Figure 1 illustrates the range of dimensions that are considered.

The field of nanotechnology and science is, by definition, extremely broad and covers everything from electronics, sensors, healthcare products etc through to micro electronic mechanical machines (MEMS). This nano world is not just a promise of greater things to come - though it will undoubtedly be a major factor in the wealth creation and quality of life of future of future UK citizens, but is here with us now. The opportunities for UK industry are immense as well as being extremely varied and exciting. Some have been

identified and illustrated in the Foresight document "Opportunities for industry in the Application of Nanotechnology", prepared by the Institute of Nanotechnology and published by OST in April 2000.

In the USA, as a measure of the interest and commitment by the US government, the fiscal budget for nanoscale science has been more than doubled to nearly \$500 million dollars in FY 2001 and is set to double again in the next fiscal year. Similarly dramatic spending on nanotechnology is also taking place in Japan a fact which has also spurred the EU into increased activity in the area.

In the UK, the potential of nanotechnology has been recognised. The nanotechnology taskforce of the Foresight Materials panel identified eight main areas of interest and these have been adopted in a current Engineering and Physical Sciences report. These broad themes of current research and development are nanofabrication, nanometrology, functional nanotechnology, nanomechanical devices and machines, molecular nanotechnology, particles, clusters and catalysis, nanostructured materials, and "extreme" nanotechnology.

- **Nanofabrication** encompasses the making of things with dimensions less than 100nm and involves lithographic techniques beyond what is possible by optical means. That is building from the top down.
- **Nanometrology** is the precise measurement of structures fabricated with dimensions less than 100nm. It also includes the development of such measurement techniques.
- **Functional nanotechnology** describes applications in which nanostructures are used to produce improved optical, electronic or magnetic properties.
- **Nanomechanical devices and machines** are an extension of the present day micromachines and microactuators into the nano world.
- **Molecular nanotechnology** is the technology of molecular sensing and molecular recognition.
- **Particles, clusters and catalysis** on the nanoscale promises to be a multibillion-pound industry for the 21st century.
- **Nanostructured materials** where the grain and composite size is less than 100nm offer the potential for stronger, more wear and corrosion resistant materials.
- **"Extreme" nanotechnology** represents atomic and molecular manipulation and assembly. That is building from the bottom up. This field is the most speculative but promises the larger long-term gains.

The task force endorsed the continued support of government and academic funding for all these areas. However, it has identified three areas that are deserving of special consideration. These are:

- Nano-fabrication
- Molecular nanotechnology at the biological/medical/functional materials interface
- "Extreme" nanotechnology

Nanofabrication is at the heart of the manufacturing things with dimensions less than 100nm (0.1microns). Optical lithography techniques have reached their limits and work needs to be done to extend the techniques of electron beam and X-ray lithography. The UK needs a central organisation that can devote resources to extending these technologies whilst pushing the boundaries of what is possible by lithographic and contact printing techniques. Such a centre would also need to be available to researchers from other disciplines whose control of dimensions may not be so exacting but whose materials systems are not as well developed for application to such techniques. Again such a facility would need to be available for researchers to perform their own writing of extremely small structures. A central facility is advocated because of the expense of such a range of equipment.

The work at the interface between the life and the physical sciences promises much. At present fairly sophisticated sensors can be fabricated which provide analysis on nanolitres of material in nanoseconds. Future applications of smart sensors built on semiconductor materials open up a whole new field of rapid medical diagnostics. The promise of nanostructured surfaces for tissue repair (including tendons and nerves) targeted drug delivery to specific sites in the body, as well as the ultimate lab-on-a-chip for in situ diagnostics start to become realisable. This promises huge potential savings for the National Health Service and vast improvements in quality of life for patients. Instead of the disruption and expense of hospitalisation, diagnosis of many infections should be possible in the home, using just one drop of blood. This is an area in which the UK has valuable expertise but which now needs to be nurtured and expanded.

Being able to monitor molecular activity at the level of a single living cell is the next target, leading to individually tailored treatments for disease, cures for inherited disorders, better testing of pharmaceuticals, quick identification of pesticides and early diagnosis of disease. It will even have implications for the future design of nanomachines and replacement biological structures. These are also areas with critical implications for the UK economy.

The world of "extreme" nanotechnology is in its infancy; however, the ability to build structures from the atom or molecular level up brings us into the realms of "designer" structures and compounds which are not found in nature. Also when such structures are fabricated their functional properties are often very different to the constituent parts. This again leads to the development of new fields of science and technology, such as quantum computing, which will have critical implications for cryptography and secure optical and electronic communication systems with a consequently huge impact on the UK financial sector. This is still a largely untapped field, which deserves wider support.

The UK infrastructure for nanotechnology is in general lagging behind that provided in the other major industrial countries. Whilst the UK has undoubted strengths in some of the areas mentioned it still requires further investment in the technologies identified in this report. Serious spending elsewhere in the world could cause the brightest talent from the UK to look elsewhere for support. Centres of expertise need to be established which will cater for and nurture research in these critical technologies; whether these are real physical entities or virtual centres is not debated, only that they exist. The establishment of such centres will drive the production of trained personnel in these new techniques and technologies. This needs to be underpinned by a major awareness campaign aimed at

children in primary and secondary education. Nanotechnology is an exciting area; and will inspire a future generation of scientists and engineers.

Although the application of nanotechnology is well developed in the US and several countries in Europe, and is beginning to find niche markets in the UK economy in products and goods which are used in every day life. The fact that such goods use nanocompounds or nanostructures is not well publicised. An awareness campaign needs to be undertaken to improve both better public and industrial understanding of the power of nanotechnology for the present and future health of the UK economy.

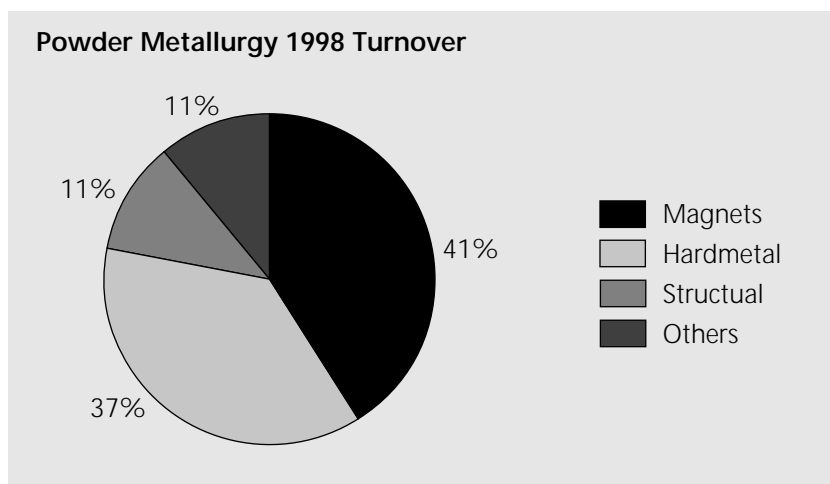
Powder Metallurgy

Background: The UK PM Industry includes production plant belonging to the largest structural PM groups worldwide, as well as several world class niche producers. With growth rates of the last 5 years of 10-15% per year, the PM sector is amongst the fastest growing metal forming industries; in many cases other metal forming processes offer no serious competition to PM.

The pie-chart below shows the split between the main applications in 1998.

The two most important sectors in terms of future prospects are magnets and structural as although the hardmetals industry is nearly as big as the magnet industry in turnover this is because of the high raw material costs the tonnage is modest and it is a mature industry with few growth opportunities. Conversely the structural components sector is more important than it appears because it is an area showing growth in the USA driven by a continuing 10% per annum increase in weight of PM parts in automobiles. This is now spreading to the European automotive market. The 'Others' sector includes some important niche market; the UK is the sole supplier of aluminium powder fuel used in the Ariane rocket and has built up a strong international position in the supply of superfine aluminium powder for metallic pigments.

The industry is co-ordinated through the UK Chapter of the European Powder Metallurgy Association ("EPMA") in conjunction with the UK Magnetics Society and the British Hardmetals Association.



IMPORTANT APPLICATIONS OF PM PARTS OVER THE NEXT TWENTY YEARS

Changes in the use of PM will be driven largely by the automotive industry although there are also important applications in electronics. Most of the applications are for relatively small parts.

Improved performance has enabled PM magnets to replace cast magnets

The challenge is now to meet the increasingly stringent needs of sensors and controllers for fuel injectors, ABS braking etc.

- Rare Earth magnets are dependant on PM techniques and enable production of small motors for operating items such as car windows
- Improved Rare Earth magnets will higher temperature tolerance extending their application in hot climates

PM rotors are established as blowers for compact automobile air conditioners. These will become standard on European cars as they are already in the USA.

PM HSS valve seats based on UK technology are the material of choice on new models of automobile and are being extended to diesel engines

PM Stainless steel exhaust flanges are a key element in meeting the latest US Auto emission regulations, showing superior performance at competitive cost compared with cast or pressed components.

Aluminium PM parts are finding increasing use in automobiles

Al foams will have increasing importance in lightweight impact resistant parts

KEY REQUIREMENTS

Workshops and questionnaires over the last two years have established the need for a whole Supply Chain approach to the design and use of PM parts. The main priority areas agreed are shown below and progress is being reported on the IOM website:

GENERAL

Education: End user engineers and designers to be made aware of the full potential of powder metallurgy process through courses in science and technology
Educational aids and material to be developed; Senior management to be made aware of developing environmental legislation through a co-ordinated system of EHS management awareness seminars.

R&D: Form a group to focus industry needs and relate these to solution providers in the UK in PM
Create a database of UK university and RTO capacity and expertise in PM

Production: Barriers to consistent quality have to be overcome
Powder Handling from Hopper to Die is a major source of inconsistency
Modelling of both die filling and powder compaction needs developing
Benchmarking to incorporate data from recognised leaders in Europe.
MIM is being used for complex parts but has yet to reach its potential.

Marketing: Good technical support is essential

Establish the potential for PM products in the fast growing “ ageing population” and “ safety/security” markets

Environment, health and safety: A standing committee should be set up to monitor developing legislation Include representatives from several sectors

STRUCTURAL COMPONENTS

R&D programme on density improvement to enter new high volume markets

Substitutes for nickel need to be developed

The UK lacks a PM Centre of Expertise

Establish the effect of design trends in automotive engine and transmission away from mechanical devices to electrical and electromechanical

MAGNET SECTOR

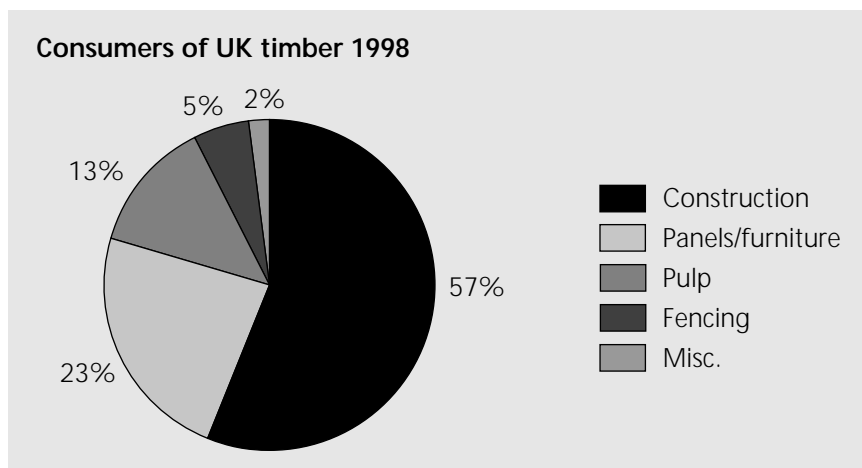
New high-energy magnetic materials are needed to satisfy automotive and other markets particularly in respect of temperature stability and corrosion.

Wood

Wood is an ideal sustainable structural material and the wide range of types available give it great versatility. This strength is also a weakness in that the diversity has led to a complex supply chain and poor understanding of its standing relative to competing products.

Industry size: Over 20 million cubic metres of timber & wood-based products are consumed in the UK each year with a value of £7 billion of which approximately a quarter is home grown. Production of wood from UK forests is expected to increase by 50% over the next 25 years as existing plantations mature. 90% of this production is softwood and deliveries of UK hardwood are declining.

This presents a significant challenge to sawmills and timber users if they are to maximise returns from this opportunity. The pie chart below illustrates the relative importance of the main wood consumers in the UK.



If imported wood products were included these figures would change but the two industries best able to exploit the increased UK timber production are construction and panels/furniture. Expansion of the use of wood in construction industry is likely to be by substitution for materials such as steel or concrete with a more sustainable product while growth in the panels/furniture production will lead to import substitution. Importantly manufacturers of fibre board and laminate panels recycle wastes and co-products from construction, sawmills and forestry.

KEY REQUIREMENTS FOR INCREASED USE OF WOOD

The diversity of uses for wood is a weakness as well as strength in that information on properties and advantages is spread across numerous trade associations who often compete with one another. Similarly while the supply chain is well established, it is complex and promotion of wood to the ultimate customer is in the hands of designers, builders and architects for whom wood is just one of a number of competing materials. The industry therefore has to increase co-ordination of research and marketing if it is to improve its position.

Market research is needed to establish the potential for wood products against competitive materials and for the different forms of wood product in view of the widely varying recovery of timber to final product; the Forestry Commission quotes conversion factors from 1.6:1 to 3.7:1 in constructional materials.

The industry's total UK spending on technical research is only £22 million which is inadequate for such a large industry as well as being dominated by forestry. Increased market research should drive a more focussed approach based on user requirements. Key areas include:

- Benchmark wood against its competitors and constructional standards/codes.
- Cost reduction at all stages of the supply chain.
- Property enhancements (e.g. fire resistance, glues & longevity).
- Life cycle analysis to promote wood as an eco-friendly product.

Despite the uncertainties, it is widely accepted that a great part of the future of timber construction lies as a load-bearing material. Educationally this would be fostered by a centre of academic excellence that would train timber engineers in a similar manner to the graduate foresters.

Long term planning is needed to be integrate the intrinsically long timescales of forestry with envisage changes in market requirements which affect both the numbers and types of trees planted.

FOLLOWING UP CURRENT INITIATIVES

DETR has summarised the options for the wood chain in a discussion paper and the industry response to this agreed the over-riding need for co-ordinated response throughout the supply chain.

The Timber 2005 plan led to the formation the Timber Industry Alliance (TIA) which has had mixed success in bringing together the 27 trade associations but is now adopting a more focussed agenda and every effort should be made to enable it to become a more effective mouthpiece.

TIA has formed a timber promotion group with target funding of £3 million per annum and support from all sectors of the supply chain; promotion will cover Internet publication to give a flexible response to continual changes in standards as well as paper & CD publications for use in design offices. . Communication with important clients has been fostered by TIA 'flying squads' using teams from several sectors of the supply chain and this will be further developed.

Co-ordinated technical research is exemplified by BRE's TF2000 project in which a 6-storey timber frame building was constructed at Cardington; this has successfully promoted this technology. This initiative needs to be followed up by other demonstration projects though not necessarily on this scale. Industry representatives have identified some important research objectives addressing aspects of the key areas outlined above and these now need to be prioritised. One issue that might be looked at is the role modelling might play in helping wood to be accepted as an engineering material.

Packaging Materials

The importance of packaging is brought home with the realisation that in the developed countries food spoilage and damaged goods is 2-4%, whereas in the developing nations the figure is 30-50%. In the UK the packaging sector is the 8th largest manufacturing sector, with a value in 1997 of \$13.5 billion (US), and for this reason it was given special attention by the Materials Panel. The Task Force comprised leading experts representing the full range of participants including researchers from the raw material companies, moulders and fabricators, the retailers, and the recyclers. In addition the DTI sponsored a "mini-mission" to access US packaging strategies and visit some of their more active companies

The globalisation of demand and environmental compliance will influence trends in packaging with e-commerce and e shopping being an important issue. This is more highly developed in the States than in Europe, and it is projected that in 5 years 20% of "supermarket" shopping will be web-based. There is also a conflict between "added value through customisation" and "cost reduction through scale". Another difference between Europe and the States is that the US clearly puts greater emphasis on technology and innovation.

Interesting predictions that are already beginning to happen are in the convenience food market, which is being shaped by packaging that will interface with intelligent household appliances. Some of the technology trends will be in low cost tracking devices, digital printing, and improved raw materials, all with the objective of product differentiation and branding, all at minimal cost. As digital imaging technology (an area where the UK has a leadership role) develops, it is anticipated that an increasing number of packaging

machines will be fitted with digital printing heads and will effectively become combined printing and packaging machines.

Control of molecular structure, to change performance by improving functionality for adhesion, impact strength, barrier performance and clarity, will be sought. Pouch packs are already being seen and food cans are coming under attack from pouches with zippers, because product processing is cheaper and capital costs are lower.

Smart packaging developments will increase with either "active" packaging, that is triggered by some event (e.g. filling, exposure to UV, release of pressure), or "intelligent" packaging, that can be switched on and off in response to changing circumstances (breathable polymers, thermochromic inks, bottle alarm caps).

Surface Engineering

The Surface Engineering Committee of the Institute of Materials has produced a report highlighting the contribution made by surface engineering to key industry sectors and some challenges for the future. The full report can be viewed on the Foresight website.

Surface engineering is a critical technology underpinning the competitiveness of UK industry. The UK market for surface engineering processes in 1995 was estimated as about £10bn, of which £4.5bn was 'engineering' coatings to improve wear or corrosion resistance. These treatments critically affected manufactured products valued at £95.5bn (about 7% of UK GDP). On current trends, the equivalent values for 2005 were conservatively predicted as £21.3bn and £143bn respectively in 1995 prices. Particularly strong growth was predicted in the aerospace, agriculture, automotive, electrical consumer goods, and electronics sectors.

The report concluded:

"Surface engineering provides one of the most important means of engineering product differentiation in terms of quality, performance and life-cycle cost."

Some idea of the pervasive influence of surface engineering can be gathered from a review of the topics identified by the Delphi survey conducted as part of the first Foresight exercise. Of the 80 topics listed in the materials survey at least 15, in sectors including biomaterials, power generation, offshore, and electronics, will require surface engineering solutions, while another 25-30 will involve surface engineering to a significant extent. Estimates of the cost of wear and corrosion to the UK and other economies suggest that these costs are a significant fraction (up to 4%) of GDP. Despite the widespread view that the situation has improved since the classic assessments of Jost and Hoar, effective use of surface engineering, coupled with improved education of designers, has the potential to deliver sizeable economic benefits.

BRIDGING END-USER SECTORS

Surface engineering may be defined as:

"The design of surface and substrate together as a functionally graded system to give a cost effective performance enhancement of which neither is capable on its own."

This is by definition a highly interdisciplinary activity. The successful implementation of surface engineering requires an integrated approach at the design stage, involving collaboration between design and surface engineers, as is increasingly being realised by managers in diverse industry sectors. In addition to being able to solve problems, surface engineering technologies have the ability to supply added value and thus add profit. The aim in surface engineering is to manipulate appropriate technologies to achieve optimal surface property designs for specific applications in the most cost-effective manner. Surface engineering thus has the ability to act as a bridge, transferring technology and expertise between end-user sectors that would not normally benefit from this cross-fertilisation. The interaction between design, properties, surface engineering technologies, and industry sectors has been summarised using the 'road map' concept

KEY AREAS FOR DEVELOPMENT

Key cross-sectoral issues identified include:

Environment and sustainability: Surface engineering offers materials savings and environmental benefits in numerous applications, e.g. through increased service life, reduced emissions and energy consumption, improved recyclability. Many modern surface engineering processes have low environmental impact. An increasingly important activity is the reclamation and recoating of expensive components. **Environmental legislation** will continue to be an important driver for change, particularly in sectors where small companies predominate. Restrictions and cost penalties on emissions and disposal/landfill will render some established processes and product life cycles unsustainable; development of alternatives will be a priority.

Lightweighting: The drivers to reduce weight will increase, particularly for motor vehicles. Aluminium, magnesium, and titanium alloys all require surface engineering to improve corrosion and tribological properties; here and elsewhere, duplex treatments (combinations of surface engineering technologies) will become more important. The surface engineering of polymers for structural applications has strong potential for growth.

Smart layers and structures: Applications of functionally graded structures capable of a response tailored to their environment will increase. This will involve further growth in use of sensors, but also applications such as smart oxidation resistant layers for gas turbines, self-monitoring buildings, food packaging, etc., in all of which surface engineering will play a key role.

Process robustness: Surface engineering processes and process-property relationships need to be better understood. This will improve process control and quality assurance, and hence productivity and customer confidence. Modelling will play a major role in this process. Generation of assured design data is a priority.

Cost effectiveness: of some important surface engineering technologies could be improved by process development to increase deposition rates and/or move from batch to semi- or fully continuous processing.

Education and training: Engineers must be made more aware of the potential of surface engineering and its integral role in design: mechanical engineering courses should include this topic. Similarly, surface engineers should receive training in manufacturing engineering. The mismatch between industry requirements and academic expertise identified and in particular a lack of expertise in 'traditional' surface engineering technologies, is a cause for concern. The LINK Surface Engineering Programme was effective in promoting university- industry collaboration and should be revisited; however, the lack of pilot scale development facilities in the UK is felt to hinder technology transfer.

Steel

Steel is the world's dominant metal and is a highly recycled and recyclable material. Steel processing, products and applications are subject to extensive innovation, improving efficiency, continuous change and improvement, in response to the ever increasing demands from users and increasingly severe operating conditions and environments. Its primary processes utilise a high degree of sophisticated control procedures. The steel industry is an extensively knowledge based activity.

The global demand for steel is expected to continue to grow - even a modest growth requires a substantial investment in new manufacturing capacity. The growth in primary steelmaking capacity is expected to be concentrated closer to the sources of iron ore and in newly industrialised countries.

Steel is used in many diverse markets that are vital to UK competitiveness, sustainable growth, quality of life and to the current needs and aspirations of society and industry.

A possible long term scenario is for the UK steel industry to move towards producing a higher proportion of steel via the 'scrap' based electric arc furnace (EAF) production route, using recycled steel as its feedstock basis, with a reduced dependence on integrated steelworks converting iron ore by carbon reduction, as these major assets reach the end of their viable lives. Bulk integrated steelmaking is still likely to have a major role, but will require new process technologies. Whatever, further technological development of both mini and bulk steelmaking routes will be required. This proposition of an increase in production via the EAF route is contrary to the recent/current closure of electric furnaces in the UK, a major contributory factor being the high UK electricity prices compared to mainland Europe. Among the major stimuli for an increase in EAF production are climate change, trends towards regional and localised production and avoidance of transporting raw materials over large distances. An increased utilisation of renewable and viable nuclear energy sources at competitive prices would help to preserve a UK based steel industry and would contribute to sustainable development. An agreed methodology is required to provide the basis for a quantification of the environmental impact and sustainability of materials.

The UK should participate actively in international research and development on the hydrogen economy both for the reduction of iron ore and to replace fossil fuels for energy purposes.

As materials suppliers move “downstream” becoming involved with the technologies associated with the use of materials, the UK steel industry will have an increasingly important role in maintaining a healthy UK manufacturing sector. The UK steel industry is expected to move even further towards higher added value products, systems supply and knowledge management, whilst also ensuring adequate returns from high volume, lower value products. The steel industry and its supply chain, therefore, needs a continued supply of skilled metallurgists, materials scientists and engineers who are adaptable, creative and capable of working in a multidisciplinary environment. Urgent action is required to reverse the reduction in materials science/metallurgy graduates. This has to be addressed at all levels of education.

The creation of a UK Centre for metals research is necessary to maintain and develop the basic understanding of metals processing, properties and performance, and to act as a focal point for technology transfer to the supply chain. This Centre would be a hub and spoke arrangement to ensure that existing expertise in industry and academia is effectively networked. The steel industry is concerned at the reduction in individual undergraduate courses in metallurgy and materials science offered as a single honours subject by UK Universities

A related UK Centre on materials modelling - for seamless modelling from the ab initio level through processing to products, properties, design, fabrication and performance is also required and supported by the steel sector.

Increasing the uptake of net shape and near net shape processing will require continued investment in metallurgical, engineering and control technologies.

More sophisticated sensors and control systems will be required to give on-line measurements and data under extreme conditions of temperature and speed. These will be integrated into the models referred to above and will be used to produce new products and more consistent products.

The UK steel industry will need advanced processing and surface engineering technologies to produce functionally graded products, ‘smart’ products and high value products.

Steel intensive systems and applications will be increasingly designed for disassembly, reuse and recycling. This will require creative individuals at the interface between materials, design and manufacturing disciplines.

Low cost rapid prototyping techniques are required for steel products subjected to various fabrication techniques, e.g. forming, joining and machining.

The development of the Internet already used extensively by the industry, for e-business, product data exchange and education/learning will be of considerable importance to the steel industry.

It is vital that the UK steel industry continues to develop vigorously in order to maintain and capture an increasing share of the world market, especially in high value products and in knowledge management and exploitation of its intellectual property.

Institute of Materials Associate Programme

The Associate Programme of the Institute of Materials (IoM) was launched in Q1 1999, with the objective of consulting and engaging the materials community in the FORESIGHT process. In all cases, the process involved end-users, specifiers and suppliers from individual and different supply chains.

The following areas were selected for action:

- a) Crime Prevention
- b) Sustainable Development
- c) Finance and Innovation
- d) Technical Textiles
- e) Packaging
- f) Process Modelling and Simulation

A BY-PRODUCT TURNS OUT TO BE THE REAL NUGGET

“The novelty value of these IoM events has been to bring together unlikely and potential partners and to confront them relentlessly with the challenges and opportunities generated through a FORESIGHT scenario. Remarkably, the outcome has been a build up of a new credibility and confidence in the innovation process” (P.W. Sinnott, UWS Ventures and Innotech Int.).

This simple and yet powerful observation provides the key to a sustainable FORESIGHT process beyond the consultation stage. Critical ingredients are the focus on end-users needs an all-inclusive approach and active stimulation of knowledge transfer and cross-fertilisation.

This message is the most important and productive output of the IoM FORESIGHT experience to date. It becomes the compelling foundation for projecting FORESIGHT into the next phase with practical realisations that will impact on the public. Sensitive to this call, the IoM has been reviewing its future plans, to turn the above message into a charter for action

THE POSITION IN DETAIL

Crime Prevention

Action under this heading was actively pursued through membership of the Materials & Chemicals Task Force of the Crime Prevention Panel, as well as through a number of independent initiatives of the IoM. The following specific areas were addressed:

Body Armour

There is considerable scope for developing a blueprint for an “ optimum performance” product. This would provide the opportunity to drive, rather than to follow material developments. The thermal properties of the armour are important for comfort and acceptability; a breakthrough in this area is highly desirable and it would rely on a combination of the properties of the constituent materials and of the construction.

Wearability is a drawback of some high performance products. A radical re-think of the way the products are assembled and the involvement of fashion and sport goods designers were identified as priority.

Key to progress on these fronts is the opening up of the challenges to a wider cross-section of the materials community through collaborative projects e.g. LINK Scheme, and the identification of the science black spots for EPSRC funding.

■ Tagging

Radio Frequency (RF) and other types of tags are widely used in the retailing sector, for inventory and security purposes. Issues associated with the environmental impact of some of these tags when used on bottles e.g. spirits have been identified.

Unacceptable discoloration of the glass can occur; moreover metal accumulation can have detrimental consequences for the recycle and re-use of glass.

The industry has undertaken preliminary steps in the assessment of the problem.

This is fertile ground for both development work through suitable academia/industry partnerships e.g. LINK Scheme, and for EPSRC support in appropriate areas of fundamental science.

■ Novel Glazing Materials

This aspect was explored jointly with the Royal Society of Chemistry (RSC) and a joint document has been submitted via the RSC.

SUSTAINABLE DEVELOPMENT

The key question here was *“What does the materials community need to know in order to respond effectively to the challenge of sustainability”*.

Two workshops highlighted the lack of a user-friendly, rational and yet simple scheme to assess lifecycle environmental impact. Such a gap exists both in the world of industry and in the educational field. Rather than fundamental science, a tidying up exercise is needed to develop two separate packages for people in the field and for teaching purposes.

In response to the above, the IoM is currently preparing the ground for an initiative to be piloted both in industry and in academia.

FINANCE AND INNOVATION

Workshops and surveys of SME's had highlighted the difficulty in accessing capital in the range £0.5-2M. Moreover, there was consensus between technologists and financiers, that a better platform could be developed for bringing the materials and the money communities together.

Jointly with the RSC, the Engineering Council and the IOP, the IoM in conjunction with banking institutions, has finalised the format of an initiative aimed at bringing small groups of people together, periodically and on a regional basis. Support for the scheme will be sought with the relevant RDAs.

TECHNICAL TEXTILES

An extended sampling of the "sector" was carried out. It soon became apparent that the use of such an inclusive heading is inappropriate and artificial. In general, 'technical textiles' operators prefer to identify themselves with the different application/product areas, and not with the common raw material i.e. fibres. From a practical viewpoint, it is easier and more effective to pursue the contacts under the sub-headings of Healthcare, Leisure & Sport and Industrial Products.

Three common themes emerged from the consultations. Firstly, the value in having a Centre of Expertise where to refer leading edge technical issues. Notwithstanding the definition of the scope and focus (in the light of the above considerations), the newly formed Faraday Partnership (TechniTex) meets this requirement. The fragmented nature of the whole area of "technical textiles" clearly poses a challenge for TechniTex regarding the definition of its scope and priorities.

Secondly, most of the operators appear to be positioned in narrowly defined supply chains, thus limiting the scope for cross-fertilisation and for growth into new markets. Thirdly, with few exceptions e.g. advanced composites, the interchange with the field of bulk materials is historically very limited. Tackling effectively these limitations would inevitably mean a strong demand for collaborative projects and for new science - of relevance to the LINK Scheme and to EPSRC.

However, there is a compelling need to catalyse changes in outlook and perception, prior to reaching a satisfactory operational basis. This is part of the agenda of TechniTex, but the magnitude and nature of the task, make the involvement of professional institutions like the IoM, IOP etc., a necessary pre-requisite for the sector to articulate and take ownership of its future.

6 | The future is theirs – Foresight and Young People

The panel recommends that there is an integrated approach to encouraging students at school to become involved with industry and the innovation process. This might be administered under the newly formed Learning and Skills Councils. It is important that initiatives such as Young Foresight, Industrial Trust, Neighbourhood Engineers, Education-Business Partnerships, Children Challenge Industry along with other national and regional activities proclaim a coherent message in line with the national curriculum. It is essential that teachers have the minimum amount of difficulty in accessing this help and that all activities should be of the highest professional standard. It is suggested that there be a quality benchmark so that teachers and schools can be confident that the educational and administrative standards are not compromised and that an exciting and engaging experience of science, engineering and industry is portrayed. It is recognised that most professional engineering institutions also administer schools programmes and thought should be given via the Engineering Council on how these can best be mobilised to raise the awareness of how engineering and industry can contribute in a positive and sustainable way to modern life. Other organisations such as The Engineering Employers Federation and relevant Trade Unions should also be involved with the Professional Institutions to take forward the issue of Life Long Learning to all levels of the engineering profession.

Tomorrow's Materials

In April 1998 a working party of the Materials Panel produced a document aimed at getting business people thinking about the future and the materials developments and opportunities that would arise. The style of the document was deliberately visual and was an enormous success. So much so that a number of people including teachers asked us if we would prepare a schools edition that they could use as a resource particularly in the design and technology parts of the curriculum.

The *"Tomorrow's Materials- Schools Edition"* and associated Teacher's Notes and Pupil worksheets, looks at number of areas of technological activity that make extensive use of developments in materials technology - such as aircraft, biomedical implants and exploration. It describes how materials have been used, are being used and might be used in the future. It also describes two design strategies useful for developing future products and includes other information such as a glossary and useful websites.

Lord Sainsbury
launched the pack
at East Barnet School
in February 1999



Tomorrows World Live

As part of this project a link was established with the BBC's Tomorrow's World Live Event being held at Earl's Court from 30 June to 4 July 1999.

Three schools were selected from those entering a competition run by BBC Haymarket to work with AEA Technology or Nottingham University to develop ideas for future products using "Tomorrow's Materials".

The University of Nottingham worked with Kirkby Centre School where two groups of pupils were involved in a project looking at the issues surrounding the materials used in making cricket gloves.

AEA worked with two schools:

Merrill College, Derby where pupils undertook a project looking at use of materials to improve the comfort of customers on trains.

The John Mason School Abingdon where pupils worked on 2 projects concerned with environmental issues. One group investigated methods for improving the recycling of everyday materials and the second the possibility of using windows as artificial as well as natural light sources.



Stand at
Tomorrows
World Live
1999

The Work of the Materials Panel Education and Training Issues Taskforce

In considering Education and Training issues, the Materials Panel elected to focus its available resources on 13-16 year olds in secondary education in England and Wales. The key question was:

"How to promote the understanding and teaching of materials in schools".

The reasons for selecting this age group and question were:

- Evidence (often, unfortunately, anecdotal evidence) that industry is not receiving enough good materials graduates.
- That Universities were not attracting enough applicants to fill their materials courses and thence meet the needs of industry.
- That therefore there is a need to 'sell' materials into schools.
- Finally, that working with Schools integrated well with the Young Foresight and Visions-Online initiatives.

The Panel of course, recognises that this issue is a subset of the general decline in a number of UK undergraduate science and engineering students on which a great deal of thought and energy has been focussed by the Engineering Council and others.

The Panel also received a submission concerning the Education and Training of Technicians and Incorporated Engineers; it is hoped to take this work further during the next phase of Foresight.

Data Collected

Over a 15 month period, the small Task Force collected data from personal interviews with teachers, from questionnaires sent to 1% of secondary schools in England and Wales, from targeted questionnaires aimed at materials professionals in secondary education and from responses to the Panel Consultation document.

Whilst direct interviews were valuable and questionnaire responses exceeded expectations, the Task Force found it difficult to engage teachers. We conclude that ignorance of Foresight or lack of time/enthusiasm to question the status quo lie behind this disappointing situation.

A sample of almost 300 groups of students (predominantly science/technology students in the 11-14-age range) were also interviewed.

Conclusions

Image and Perception

There is no reliable data on the shortages of materials technologists in industry. The excellent data collected by the Engineering Council and the Engineering and Marine Training Authority is too coarse to pick up information on small subsets of engineering such as materials. There is certainly widespread anecdotal evidence of shortages, especially since so many graduates, being both numerate and practical, are attracted to the City. There is danger of companies doing without specialist materials technologists rather than competing for the few available; this would spark a downward spiral in the profession.

Engineering generally is not perceived as 'exciting'. Extensive research by others into student perceptions suggests that engineering has no scope for individuality and novel advances. We found an acceptance that the UK needs engineers and that many are well-paid professional jobs, but they are difficult, often perceived as dirty and just not exciting.

Fewer students are taking GCE 'A' level physics, the traditional foundation of an engineering degree course. Again, much research has been conducted but it appears that physics is seen as difficult leading to a career which is also difficult. (Sadly, physics is also perceived to be male-dominated). On a more encouraging note, Design and Technology is perceived as a 'soft option' and many GCE A-level D & T courses, possibly because of the IT content, are oversubscribed.

There is a widespread feeling amongst the Task Force and teachers (again supported by educational research), that pupils are subconsciously making the 'arts/science' decision at around Key Stage 2. Pupils of this age love to be astonished; materials lends itself to this and the National Curriculum provides the opportunity.

Curriculum

We received many diverse views on the benefits of the National Curriculum. However, there was a unanimous view that the Curriculum is too full with time being eroded through the excessive focus on numeracy and literacy. Certainly most teachers felt heavily constrained (maybe through lack of time, confidence or experience) by the Curriculum. Furthermore, pupils are aware of the contents of the Curriculum and will only, by nature, work to achieve the minimum requirements.

Hence, to successfully raise the profile of engineering (particularly materials engineering), there needs to be greater focus within the Curriculum and a higher profile with the Examining Boards. Here lies the problem. A strength of materials is its broad-ranging, multi-disciplinary nature. But this is also a great weakness because it "lies in the no-man's land between technology and science". Whilst the topic 'materials' features in the Science Curriculum, most of the content has a strong physics or chemistry bias and will almost inevitably be taught by those with a traditional physics/chemistry background.

The D & T syllabus is very applied in nature and does not extend, for example, to an understanding of the properties of materials.

In response to our student survey, over 99% claimed to understand what 'materials' are, with 70% meeting 'materials' in D & T, 25% in physics, 27% in chemistry and 37% in science (pupils could select all subjects that could apply).

The new AS-level qualification appears to be a good opportunity to provide a broader understanding of materials. There seems to be scope to provide good quality teachers' notes, documentation and project proposals for the AS-level D&T course. An initiative to encourage supplementing the traditional Maths/Physics/Chemistry 'A'-level courses with AS-level D&T would also promote design skills amongst otherwise 'pure' scientists and engender a more quantitative, analytical approach to design projects, making practical use of the theoretical mathematics and physics learned in the classroom. An AS-level focussed on materials engineering may also be possible.

Teachers

The Task Force were struck by the poor communication within schools. Without doubt, the per capita method of funding departments leads to insular teaching and rivalry. Though most teachers accepted that it would be beneficial, we found little evidence of co-ordinating teaching e.g. between physics and D & T.

There were concerns about the shortage of physics teachers and some documented evidence to suggest that the qualifications of those teaching physics are somewhat below the average for other subjects.

Teaching Resources

A great many responses highlighted a lack of funding. One D & T department has an annual budget of £50 for materials and £500 for equipment. Average budgets seem to be in the range £2-4 per student per year. For D & T, a mandatory National

Curriculum subject based on making artefacts, these figures, if representative, seem unbelievably low.

One D & T teacher jealously guarded his Thursday free period since it gave him time to go through the waste skip at a local scrap yard looking for materials for his student projects. Hardly an example that will encourage students into engineering!

Some teachers referred to a history of under-investment, particularly in updating workshop equipment ... "archaic equipment creates an archaic image". The Task Force felt that there was scope for encouraging industrial funding, possibly by a schools equivalent of the Joint Infrastructure Funding (JIF) that has been available to Universities.

In terms of teaching resources that would help enhance the profile of materials, the most popular on the teachers' 'wish list' is cheap, readily available specimens and testing equipment.

Simple booklets, matched to the Curriculum, would be helpful. 'Tomorrow's Materials', sponsored by the Materials Foresight Panel, was warmly praised with 93% of those receiving it finding it useful. Sadly, despite providing multiple copies to every secondary school in England and Wales, only 22% of teachers and only 4% of pupils had seen the publication.

CD-ROMs, with cheap, multi-user licences, were preferred to web-based media, largely because of cost. Such CD-ROMs need to be interactive, multi-level, competitive, high quality and specifically tied to the National Curriculum. Videos showing materials processing and testing in short sequences would also be useful.

Many teachers asked for a comprehensive list of good materials web sites, though student access to the web is very variable in schools.

Finally, visiting speakers and particularly factory visits are very difficult to organise within the cost and time tabling constraints. Although those schools which had made factory visits found them very informative.

Recommendations

A regularly updated labour market survey in materials and related disciplines is required to demonstrate the commonly held belief that there are inadequate materials technologists to meet industry's needs.

ACTION: Institute of Materials

Industry needs to do more to safeguard the supply of engineers for the future. Working with Government and the Professional Bodies (through the Engineering Council), industry must take the lead in promoting the importance of engineers.

ACTION: Industry/HMG/ Engineering Council

Government should invest more in school infrastructure to facilitate the teaching particularly of D & T in a modern environment. The schools equivalent of the Joint Infrastructure Fund, sharing the cost with industry, seems worthy of consideration.

ACTION: Industry/DfEE

Government should continue its efforts to encourage good quality physics graduates into teaching. Differential pay, use of retired industrial staff and 'travelling road-shows' should be considered.

ACTION: DfEE

A concerted attempt, in conjunction with the Examination Boards and the Curriculum Authorities, should be made to teach engineering as an identifiable subject.

Consideration should also be given to encouraging Maths/Physics/Chemistry "A level" students to take AS-level D&T.

ACTION: Engineering Council/ DfEE

Consideration should be given to providing additional, focussed teaching aids at all levels from KS2 to AS-level.

ACTION: Institute of Materials

Finally, a comparison of the status of engineers in the UK with other selected countries should be undertaken. This should include analysis of teaching methods and curriculum content in schools.

ACTION: Engineering Council/ DfEE

7 | The international scene

It has been the intention of the Materials Panel to try and review Materials Foresight Activities in other countries. This has been partially achieved and will continue to be pursued. At a meeting in February 2000 the First International Conference on Technology Foresight was held in Tokyo. The worldwide activity is gaining momentum with over 20 different countries participating. The proactive approach of the Materials Panel was seen as innovative since the need for increased investment in Materials Research and Training was one of the universal themes of the analyses from most countries. A recent mission to China to attend the 2nd High Tech Fair in Shenzhen found that Advanced Materials was one of the two main themes with many of the activities paralleling those of the UK. Further information on how to make contacts in China can be obtained from the DTI.

This short section contains an analysis of the EU's "Futur" programme with respect to materials and a listing of the current Japanese priorities.

Since Japan pioneered the idea of a strategy for technology nearly 30 years ago there has been a significant worldwide uptake of the concept. The activities that have developed have typically follow the OECD definition of Foresight which is:-

"a process involved in systematically attempting to look into the longer term future of science and technology, the economy and society with the aim of identifying the areas of strategic technologies likely to yield the greatest economic and social benefits."

This is very similar to the UK Foresight objectives and with its roots in the Delphi process of technology evaluation. The participation and interest is now so great however that an international "Foresight" conference was held in Tokyo in March 2000 to compare and contrast the worldwide progress. This section draws heavily on that meeting and also on a report by Cahill and Scapolo for the European Commission ("The Futures Project" - EUR19031EN) method. Although this "comment - review - refine" technique was developed by RAND in the early 1950's, it was Japan that devised and established the approach of a large scale survey covering every field of science and technology and involving thousands of experts. The number of topics and fields have increased over the years, but have always included materials and their processing (table 1)

Table 1: Changes in the Coverage of Japan's Technology Forecast Surveys

	Survey Period	Fields	Topics	Forecast Period	Effective Responses
First Survey	1970 - 1971	5	644	1971 - 2000	2482
Second Survey	1976	7	656	1976 - 2005	1316
Third Survey	1981 - 1982	13	800	1981 - 2010	1727
Fourth Survey	1986	17	1071	1986 - 2015	2007
Fifth Survey	1991	16	1149	1991 - 2020	2385
Sixth Survey	1996	14	1072	1996 - 2025	3586

Table 2: Summary of National Approaches to Foresight

Country	Method	People Involved	Time Horizon	Technologies Listed	Link to Policy
Japan	Delphi	2,385	25 Years	400+	Strong
UK	Delphi, Group	500	15 Years	150	Strong
France	Group	50	10 Years	100	Moderate
Germany	Delphi	200	10 Years	35	Weak
USA	Survey, Group	40	5 - 10 Years	100+	Weak

Indeed the local experience of previous Swedish and German work has already shown us the following additional pitfalls: -

- The project managers need to be first rate to succeed
- The methodology must be flexible to cope with different topics' needs
- Knowledge pools suffer from lack of resources
- Participants cannot find enough time to commit to the project
- The short term benefits are often not enough to gain resource priority
- Participants have different personal objectives
- There are no simple metrics for "success"

However, the processes in place do lead to change and in particular in Austria, the following visible impacts are claimed:-

- New programmes in sustainable production and transport
- The creation of new ("K-plus") competence centres
- A new green paper on research strategy
- Stimulation of sectoral Foresight projects

- Plans for further IT analysis and follow-up
- New research centres in recommended fields e.g. wood
- Transfer and distribution of results and ideas

For materials, there is still some way to go. IPTS concludes that on a scale where the USA scores “four stars” for its technology strength, Japan rates three and Europe only two. Cahill and Scapolo put this down to weaknesses in chip production, photovoltaics, batteries and ceramic materials generally. It is also interesting that at that time (the end of 1999), only USA, Japan and Korea had nanotechnology as a key priority. Cahill and Scapolo do note however that:-

“ The long development time and slow return on materials research investments make industry somewhat reluctant to take on the associated risks alone. This makes materials an ideal area for policy initiatives with regard to the sustaining of long term research efforts and the stimulation of wider co-ordination of effort and the networking of actors (sic)”

They summarise the position in table 3 and conclude rather sweepingly that “ materials represent the major bottleneck for the developments of all other technological areas” .

Table 3: Europe's Position in Relation to Emerging Technology

Materials Technology	European Strength or Weakness	Importance Index
Implant material that lasts a lifetime	Moderate	83
Temporary bone fixation material	Moderate	82
High performance switching elements made from third order non-linear optical material	Weak	82
Signal responsive missile drugs	Strong	81
Biodegradable plastics	Very Strong	76
Diagnostic technologies for estimating remaining life of mechanical components	Weak	76
Computer simulation technology for growing thin films from first principles	Strong	75
Semiconductor UV lasers	Very Weak	70

It may be though, that an even greater influence exists, namely people. They do highlight that the connection between people and technology is critical to successful technology exploitation, but even more it seems that the future of Foresight is in satisfying the changing needs of people not vice-versa. It is well summarised by Luke Georghiou in his paper in Tokyo, "Third Generation Foresight - Integrating the Socio-Economic Dimension". It is also reflected in the aims of the Japanese "Seventh Survey" just underway with the direction of a "needs" approach and the basic tenet that society will control our technology and not the other way around. In summary, it is clear that the Foresight process, rather than having run its course, is probably only just starting.

8 | What next?

The panel hope you will have captured some of the widespread activity that is now ongoing within the materials community. There is considerably more to be achieved and the panel will be tackling some of the more obvious deficiencies. The impact of Regional Foresight is still to be experienced. This is intended to bring in smaller organisations and supply chains. There will be massive changes in the way continuing education is delivered. The Committee of Vice-Chancellors and Principals have produced documents on "Borderless Education" which challenges the idea of a university being geographically identifiable. The continuing application of environmental legislation, the influence of genomics, how healthcare is delivered and many more unknowns will all have impact on the materials supplier and user communities. All these developments uphold the continuing need to develop the Foresight process still further. Young Foresight and other initiatives will start to embed the process among young people. Training the trainers and the parents will be the next step.

Acknowledgements

To thank the vast number of people who have given their time and effort into the Materials Foresight process would be an impossible task. To some extent this is encouraging since the numbers involved in detailed discussions number at least several hundred if not more. They are cascading the message down to a level that the panel could never reach. Specific thanks must go to the "Foresight Champions" who have led such exercises. I hope their own sector acknowledges this appropriately.

We are indebted to the various Associate Programmes for widening the basis of the Foresight Exercise and encouraging their members to participate.

I would like to personally thank the panel members from the first and second rounds who have been a pleasure to work with. We have shared our laughter and disappointments in a constructive way and it has been a privilege to work with them. This has been aided and abetted by the support we have had, first from Brian Ferrar and latterly from John Baker who have serviced the panel during the last four years.

Finally I must thank my own institution, The University of Nottingham, for allowing me the time and space to lead the panel and to my close colleagues who have had to take on extra burdens, often at short notice, to allow me to give the appropriate energy for the cause. I know colleagues around the university cringe when I mention the "F" word, but it has been encouraging to see how the use of the Foresight Process in planning for the future has been taken up especially within my own Faculty of Engineering. Seeing it in action for real has been extremely stimulating.

John Wood

Appendix – Materials priorities in Japan

The following is a list of the key research areas currently being supported by funding agencies in Japan.

STA	Special Co-ordination Funds for Promoting Science and Technology	<ul style="list-style-type: none"> ■ Virtual experiments for material design project ■ Research on fundamental science of frontier ceramics ■ Frontier research on functional thin films ■ Research on new materials development based on nano-space phenomena ■ Development of assessment systems for reducing environmental impact and of designing concepts for environment friendly new materials and processing ■ Development of energy conversion materials through formation of gradient structures ■ Research related to the manufacture of new performance-adjusting oxide materials ■ Research related to the creation of biocompatible materials with directional QOL ■ Research related to the construction of the foundations of a system for promoting the commercialisation of internationally advanced materials ■ Research related to establishment of the foundations of a system for predicting the safety characteristics of chemical substances
	National Research Institute of Metals (NRIM)	<ul style="list-style-type: none"> ■ Research related to structural materials (supersteel materials) for the new century ■ Materials research using SR (large-scale radiation facilities) ■ Research on evaluation of super-structures on ultra-clean surface and creation of dimension controlled nano-structures ■ Biocompatible materials ■ Research into intelligent field emission electron sources using the self-constituting control mechanisms of thin films ■ Elucidation of the mechanism of material property manifestation in the atomic probing of alloy elements embedded in advanced metallic materials ■ Research into the quantum magnetic properties of mesoscopic magnetic materials, and into spinning function elements ■ Research related to the manufacture of multifunctional materials for assembly of functional elements

	National Institute for Research in Inorganic Materials	■ New superconducting materials	
		■ Materials research using SR (large-scale radiation facilities)	
		■ Super-diamond cubic boron nitride and single crystal diamond films	
		■ Materials processing in a short-duration microgravity environment	
		■ Materials research related to self-denaturing due to external conditions	
		■ Special research on the catalytic properties of titanate-related ceramics	
		■ Clay organic composites as earth friendly materials	
		■ Research into analysis technologies for ultra-microstructures	
		■ Research into the creation of organically active ceramics	
		■ Research into the plastic processing of ceramics	
		Institute of Physical and Chemical Research	■ Frontier materials
			■ Coherent science
			■ Atom-scale sciengineering
Japan Science and Technology Corporation	■ Solid junction, polymer phasing, particle surface and other exploratory research for advanced technology		
	■ International joint research project for ceramics super-plasticity research		
MESSC	National universities and other institutions (through provision of grant-in-aid for scientific research and other funding)	■ Fabrication and characteristics of new metallic glasses and their development as engineering materials	
		■ Construction of organometallic conjugate systems, and development of their physical properties	
		■ Structural studies of novel metal and complexes produced by laser ablation of metals	
MAFF	Specific research areas	■ Development of new functional woody interior trim materials	
MPT	Communication Research Laboratory and others (Frontier Research and Development for Next-generation Telecommunications Systems Programme)	■ Applications of superconductivity to high performance telecommunication technology	
MITI	Industrial Science and Technology Frontier Programme	■ Superconducting materials, superconducting devices	
		■ Synergy ceramics	
		■ Technologies for novel high-functional materials	
		■ Supermetals, etc	

Osaka National Research Institute	Research related to structural control of Institute, AIST photonics glass
Electrotechnical Laboratory	Research related to the formation and performance of macromolecules
Kyushu National Industrial Research Institute	Research related to advanced functions for light-intensive dielectric ceramics
National Institute for Resources and Environment	Research related to processing technologies for metallic/oxide superlattice performance materials
Chugoku National Industrial Research Institute	Research related to processing technologies for high-performance diamond materials
Mechanical Engineering Laboratory	Research related to environmental response expression through merging of metallic material functions
Tohoku National Industrial Research Institute	Research related to environmental response expression through merging of metallic material functions
National Industrial Research Institute of Nagoya	Research related to technologies for formation of ultra-thin ceramic membranes using the solgel method
National Institute of Materials and Chemical Research	Research related to the control of boundary interface micro-domain reactions
Hokkaido National Industrial Research Institute	Research utilizing microgravity environments
Shikoku National Industrial Research Institute	Intelligent technology of underwater plasma processing
National Institute of Advanced Interdisciplinary Research	Cluster science

Source: White Paper on Science and Technology 1997

The Japanese Technology Forecast Survey published in 1997 highlights the following topics in materials as developing:

Organic Materials: Bio degradable Plastics, Polymer liquid crystal, Engineering plastics such as polyimide resin, Photosensitive polymer, and Polymer alloy.

Inorganic Materials: Ceramics, Ceramic high temperature superconductive, Concrete, Carbon such as carbon fiber, Diamond, and Ferroelectric materials.

Metals: Steel, Magnetic materials, Aluminium alloy, Titanium alloy, Metallic superconductive, and Hydrogen storage alloy.

Semiconductive Materials: Silicon, Amorphous silicon, Gallium arsenide, Gallium nitride, Silicon carbide and solar cell materials.

Bio Materials: Bio-compatibility materials for artificial organs and bone such as ceramics, titanium, Ensign, and DNA.

Composite Materials: Intelligent (smart) material, Inclined functional material, Hybrid materials, FRP (Fibre Reinforced Plastic), and CFRP (Carbon Fibre Reinforced Plastic).

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The Foresight Programme

The UK Foresight programme brings together the voices of business, government, the science base and others to look at what might happen in the future and what we need to do now to secure long-term competitive advantage and enhanced quality of life for all.

The programme was launched in 1993 following the Government White Paper on science, engineering and technology, Realising our Potential. It has a panel-based structure and operates on a five-year cycle. The current round of Foresight began in April 1999 and work has been carried forward through three thematic and ten sectoral panels.

Each Foresight panel looks at the future for a particular area, identifying the challenges and opportunities that the country is likely to face over the next ten to twenty years and beyond. In doing so, Foresight aims to bring about a culture change for the better in the way organisations relate to each other and to the future.

All panels consider the implications of their conclusions for education, skills and training and sustainable development.

This report - and those of the other panels - represent the culmination of over a year's intensive research, debate and discussion. They provide the basis from which panels and others will work to help turn the recommendations into action.

Foresight panels:

■ Ageing Population	■ Financial Services
■ Crime Prevention	■ Food Chain & Crops for Industry
■ Manufacturing 2020	■ Healthcare
■ Built Environment & Transport	■ Information, Communications & Media
■ Chemicals	■ Materials
■ Defence, Aerospace & Systems	■ Retail & Consumer Services
■ Energy & Natural Environment	

A further industry-led panel is looking at Marine issues and there is a task force addressing the impact of E-commerce on business processes and supply chains.

Copies of the full reports for all panels are available from the Foresight web site at **www.foresight.gov.uk** or by sending a fax to the Office of Science and Technology on: 020 7215 6715.

Foresight also supports an ever-increasing programme of activities for younger people. Further details can be obtained via the fax number above or at **www.youngforesight.org** and **www.visionsonline.org**

dti

Department of Trade and Industry



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