Executive Summary

Nanotechnology IS important.

Both Germany and the US have nailed their colours to the mast – Germany through its strategic document of 1998 'Opportunities in the Nanoworld' which highlighted key enabling technologies that would be needed to underpin industry in the future, and the US's National Nanotechnology Initiative, which in January 2000 set out a series of Grand Challenges which nanotechnology could resolve. Both were backed by substantial funds expressly aimed at funding multidisciplinary research in Nanotechnology.

The UK Materials Panel Foresight Report (November 2000) highlighted nanotechnology as its most important area of technology for future research and wealth creation. It was conscious that since the early, heady days of the UK's National Initiative on Nanotechnology (NION), established in 1986, and the subsequent Link Nanotechnology Programme of two years later, the UK has rapidly lost momentum in a coordinated approach to nanotechnology.

The aim of the Missions was to build on the Foresight Report and establish just what the reality of nanotechnology is now, nearly 15 years after NION. Is it just hype? Is there real money being invested? Are there real expectations of a return in the foreseeable future? Where does industry think the opportunities lie? And most importantly, where should the UK be positioning itself so as not to lose out.

The conclusions are – yes, nanotechnology is a reality; yes, some applications are further off in time than others; but, yes, some are already in the market place; and yes, the UK needs to be positioning itself to benefit from this emerging technology. Now.

Formulating a Strategy

If we accept the basic premise that nanoscale science and technology are important, and if the UK is serious about maintaining its industrial base. what needs to be done? Choices need to be made, based on the answers to critical questions, for example:

- Do we build on our academic strengths; or on our industrial strengths, or both; or do we need a totally new vision?
- What weaknesses, or challenges, will we need to address?
- Should we be progressing on one or two key fronts only?
- What infrastructure is necessary?
- How can a *coordinated* approach be implemented - from education to training to research to commercialisation?

Answers need to take into account some inescapable facts. The UK can't match the funding of the US, and we don't have in place an infrastructure in support of nanotechnology equivalent to that in Germany. It is also unlikely that the UK can have *world* domination in any one aspect of nanotechnology, although we could be well placed to exploit important opportunities.

Therefore, prior to making any decisions, the strengths and weaknesses of the UK education / research / industry / infrastructure / funding systems need to debated at the highest levels.

Some further issues in terms of funding need to be resolved. Germany and the US both have in place long term and short term funding for nanoscale research. In the US, high risk technology is funded by the Government. Are there lessons here for the UK?

If the UK goes down the path of playing to its academic strengths, funding could be made available to support the top scientists in the field in building up teams and equipment (as the Germans do) over the longer term, say 5-10 years. Alternatively, research funding could be focused on technologies that will support our industrial base (pharmaceuticals, aerospace, defence, opto-electronics etc), on a similarly long time scale. (This is really what the UK Foresight exercise is about, but originally Foresight had the remit of examining the needs of *individual sectors of industry*, and did not consolidate its outcomes by defining important cross cutting technologies). This omission was in some ways addressed by the booklet prepared by the Institute of Nanotechnology on 'Opportunities for Industry in the Applications of Nanotechnology, and published in April 2000 by the Office of Science and Technology).

An alternative approach could be to create a vision of the future, and make the system deliver the vision by channelling research and infrastructure funding to support it. In one way, Germany has established its own particular vision of technology, opting not to go down the route of silicon for the basis of microsystems development (a US technology), rather choosing polymeric materials.

The Joined –Up Approach

It is important not to forget that there are real strengths within the UK academic base, which could be dramatically reinforced through being consolidated into a strategic whole. The lack of a cohesive approach is apparent across the gamut of UK initiatives such as Faraday Partnerships, research-council funded networks, IRCs, UICs and so forth, which tend to work in isolation relative to each other. The UK needs a means of coordinating the activities of these through a body such as the Institute of Nanotechnology

A further disadvantage relates to the weak links in the UK between industry and academic research, and our slowness in 'pulling through' commercial applications into products and services. In Germany, there is an increasing pressure to accelerate the commercialisation process, but there still exists an anxiety that the science is not moving quickly enough into the market place. Paradoxically, the UK is seen by Germany as more efficient in its commercialisation activities.

Once the strategic approach has been agreed, further answers are needed regarding:

- What levels of funding are associated with such a strategy?
- What key actions cannot be addressed within the available funding?
- Where is the payback to the UK?
- Will proposed UK funding be significant relative to funding in other countries?
- How does the UK address longer-term horizons, arising from the convergence of information and communication technology and nanobiotechnology? It is predicted that the new sciences of genomics and proteomics, in which the UK has recognised strengths, will also have an important role to play. The marrying of these with telematics will have major implications for the UK
- How can the rate of spinouts, crucial to getting information out of the nano base, be increased?

Recommendations on Education, Training and Public Awareness

A clear message from the Missions is the need to capture the interest of the next generation of scientists. Schools need to be helped to be responsive to nanotechnology; which by its inherently exciting nature, is capable of attracting young people into science. Communicating this at the right level will be key.

There is also an agreed need for more training, through Masters courses in the first instance (perhaps by building a nanotechnology MSc, or MRes, on to an existing microsystems course). We need to take on board the lesson from the States, where 10% of the NSF budget is devoted to outreach. Informing children, teachers and the public is accepted as being of fundamental importance.

Conclusions

Nanotechnology IS important. German and US strategies reflect their own particular needs and strengths. The UK also needs a strategy in nanotechnology, reflecting **its** own needs and strengths, and, critically, a delivery infrastructure.

If the UK decides to become a player in nanotechnology we still need the infrastructure in place to support any decision, and we need to find ways of bridging the gap between research and commercialisation. If a particular focus is selected, the decision has to be rigorous to ensure the correct choice has been made, given all the evidence, and to enrol the key players. Success is also more likely with the right strategic collaborations and alliances in place.

In 1986, the UK was on the threshold of opportunity; in 2001 we are on the threshold of a major threat. There is still time to address this, however, but we need to start immediately, build momentum quickly and coordinate our activities across academe, industry and government. Given the impact that Nanotechnology will have on employment, wealth and technological capabilities in the UK, the “status quo” is not an acceptable option.

Overview

Introduction

In 1986 the UK showed a relatively early interest in nanotechnology by establishing a National Initiative in Nanotechnology (NION), followed in 1988 by a LINK Nanotechnology Programme (which encompassed a small, but farsighted, budget for technology transfer). At the end of the funding of the LINK projects in 1996, there was no longer a focus for science at the nanoscale, and nanotechnology became fragmented through the research councils. In the first UK Technology Foresight exercise which began in 1994, mentioned many areas where nanoscale technology would have application, although it was not mentioned by name.

There is much debate about what nanotechnology is or isn’t, the one feature of nanotechnology, however defined, is that of ***multidisciplinarity.*** Because nanotechnology was not specifically mentioned, by name in the research themes emerging from the first Foresight exercise, the opportunity to develop multidisciplinary projects was largely missed. Innovative research since then has struggled to find a home for quality projects that could not be pigeonholed into one discipline or another.

The omission of nanotechnology as an enabling technology in the first Foresight exercise is in the process of being remedied in the second. In April 2000 the Office of Science and Technology, published a Foresight booklet on ‘Opportunities for Industry in the Applications of Nanotechnology’ commissioned from the Institute of Nanotechnology. This was followed up in November 2000 by a booklet, produced by the Materials Foresight Panel, and also published by the OST, called ‘Materials: Shaping our Society’ which contains a clear section on the importance of nanotechnology for new materials.

The missions provides a follow up to the booklet, to determine if and how the applications of nanotechnology are actually being realised, what supportive infrastructure is in place, what funding is available, and what lessons could be learned of benefit to UK industry.

The US and Germany are seen as vital to obtaining this insight. In 1998, a strategic document was produced by the German Association of Engineers (VDI) entitled: ‘Opportunities in the Nanoworld’, which identified those nanotechnologies critical to the future of industry in Germany. Germany already had a research infrastructure in place, and only a modest ‘tweaking’ was required to meet the new challenges of nanotechnology.

Allied to the strategy document was funding for 6 Competence Networks distributed throughout Germany. Additionally, the Federal Governments funds a number of projects in areas including femtosecond technology (for nano-scale metrology and for the production of nanoparticles and nanostructures); laser-assisted high throughput screening of organic and inorganic substances; nanotechnology applications in electronics, medicine and pharmacy; and nanobiotechnology. competence centres distributed throughout Germany. In the process of being funded now are four or five further centres of excellence in nanotechnology. Germany also has a reputation for spinning out new nanotechnology companies from the research base, and information as to the forces producing commercial outcomes was a further objective of the Missions.

In the US in January 2000, the Clinton Government demonstrated its growing commitment to nanoscale science by announcing its now famous National Nanotechnology Initiative. Driven by Dr Mikhail Roco, it sought $500 million dollars of research funds from Congress for collaborative projects – receiving $422 in the FY 2000-2001, and $485 in 2001-2002. This was closely followed by an important agreement signed between NASA and the National Cancer Institute in April of that year, to jointly funding research into nanotechnology as a route to effective health management in space.

Both in the US and Germany, many companies are already commercially exploiting nanotechnology, particularly in new materials. The commercial applications of nanotechnology are the subject of a further new booklet 'Nanotechnology – The huge opportunity that comes from thinking small' written by the Institute of Nanotechnology in co-operation with Eureka - Innovative Engineering Design, and supported by the DTI, due to be published in June 2001.

Objectives of the Missions

The aim of the missions was ostensibly to seek answers to global questions, as well as identifying how the particular organisation benefited or otherwise from the nanotechnology 'climate' in Germany. Questions we were seeking answers to were:

1. what is the level of interest by business in nanotechnology?
2. what is the level of interest by funders in nanotechnology?
3. where do the major opportunities lie?
4. how is nanotechnology being applied?
5. which companies are involved?
6. how is manufacturing at the nanoscale being achieved?
7. what are the perceived benefits?
8. what new applications are in the pipeline?
9. what is the overall strategy?what are the drivers to commercialisation? what are the problems?

Focus of the Missions

As multidisciplinarity is the name of the game in nanotechnology; and because the predictions are that the next industrial revolution will hinge on the combination of bio- info and nano- technologies – the so-called BIN revolution, the theme for both missions was to concentrate on technologies at the life / physical sciences interface, particularly

- biomimetically-derived and bioactive nanostructures for applications including therapeutics and diagnostics
- devices for single cell and molecule measurements (nanoprobes, devices and tools) in the early detection of disease, drug discovery and the application of pharmacogenetics
- electronic / biology interfaces for sensors (e.g. electronic noses)
- biological nanostructures, biocompatible materials
- nanotechnology in tissue repair
- nanoparticles in drug delivery and cosmetic applications

GERMANY

Background

Germany has a very large non-university research infrastructure. Apart from activities at universities and institutes attached to universities, German research is undertaken in institutes of the Max Planck Society (79 institutes) , the Fraunhofer Society (48 institutes), the Leibniz Association (78 institutes) and the Helmholtz Association (16 national science centres). These research organisations are funded jointly by the Federal and Länder Governments on a varying basis.

There is intended to be a relatively clear delineation of function between these organisations, with the Max Planck Society devoted to pure research, the Fraunhofers to applications-oriented research and the University spin-out Institutes mainly to specific commercial topics. This distinction is becoming blurred slightly, as there is a demand from industry for the expertise within the Max Planck Institutes. The presence of an existing strong and comprehensive research infrastructure has made it simpler to add additional funding to support specific needs in emerging areas, e.g. nanotechnology.

There is also an increasingly powerful message from government that the required outcome from research is products and jobs, representing a fundamental shift in the attitude of German researchers to commercialisation, though failure in business is still unacceptable. The UK is seen as a model for entrepreneurial spirit!

Additionally, the more traditional, larger companies in Germany are also taking nanotechnology seriously, and are hedging their bets in several ways, for example, by actively seeking an involvement, either by research in-house, or through collaborative ventures with research organisations, or through acquisition. Across industry and the research base, nanotechnology is accepted as the route to building in more functionality to existing products.

Nanotechnology has also benefited from the significant funding available for restructuring the previous East Germany and the heavy industry heartland of West Germany, including Länder, Federal and EU funding, North Rhine Westphalia began to establish a large number of technology parks in the 1980s – the first in Germany – in an effort to shift activity from the traditional coal and steel industry to more innovative sectors and to encourage the establishment of new companies. There were also a number of schemes to rebuild the R&D infrastructure in the former East Germany and to promote the establishment of small and medium-sized companies in that area. Both the Fraunhofer and Max Planck Societies have established a large number of new institutes in the former East Germany. These are usually set up around an eminent scientist in the relevant field, for instance, from an existing university research group or institute. Success has been dependent on the individual and local support (as in Saarbrucken), or on the existing technological capability (as in Jena).

Microengineering and microsystems technology are seen as providing enabling technologies for nanotechnology. Because Germany has created a microtechnology infrastructure, it is well positioned to exploit nanotechnology. It was noted that the Swiss also, because of their capability in ultraprecision engineering, are well placed to develop the nanotools of the future, a role they are already embracing (with help from the Cantons). Microstructures are also seen as the route to the utilisation of 'bottom-up' nanotechnology using self assembly. This will be through a gradual incorporation into top-down, lithography-based microstructures, as a hybrid middle way before achieving full manufacturing at the nanoscale, for example in analytic and sensor applications.

Centres of Competence

From the UK perspective, Germany appears to have a well established infrastructure in the field of nanoscience and nanotechnology with many research Institutions, Universities and companies (which from their names, or from the description of their products or processes), appear to be actively embracing nanotechnology. This is borne out by examining the VDI's (Association of German Engineers') nanotechnology website at http://www.nanonet.de.

The companies and research institutions involved in the six Competence Networks created in 1988 operate in the five key areas of nanoscience as identified by the German Government as of importance – namely

- ultra thin functional layers
- developments of lateral nanostructures
- nanomaterials and molecular architectures (two networks)
- ultraprecise surface measurements
- nanostructure analysis methods

Based on the ability to manipulate matter at the atomic and molecular level, Germany sees important opportunities within the areas of ***energy engineering*** (gas cells, batteries, solar cells etc.), ***environmental technology*** (material cycles, disposal, clean-up, etc.) as well as in ***information technology*** (high-density memories, efficient processors, etc.), ***health and ageing***. - The aim is to create jobs in innovative sectors in Germany and to protect the existing ones in a globally competitive market.

Germany sees important opportunities and has strengths in nanotechnology applications for electronics and data storage systems; chemicals and materials; optics; vehicle technology and mechanical engineering; microscopy and analytics. In other important nanotechnology applications, for example, nanobiotechnology and display technology, Germany is perceived to lag behind its main competitors.

About 2/3rds of research funding is strategically directed, about 1/3rd is opportunistic. The emphasis is on applied, whilst not neglecting the more speculative. In the USA, the emphasis is on the fundamental research. Each plays to their strengths.

In Germany, the Mission only visited organisations within a subset of nanotechnology, i.e. materials and biomed, but it was clear that certain strategic decisions had been made, with long term implications. For example, the decision not to use silicon as a substrate, as this is a US strength, but to use simple processing techniques and materials, such as embossed polymers.

Conclusions from Germany

The Germans ARE serious about nano; and have in place a good funding structure; and co-ordinated approach, with useful networks and Centres of Excellence. No researcher complained about lack of funding!! Commercialisation has moved right up the agenda, and is actively encouraged and supported – a relatively recent change in approach for the Germans. Finally; Germany has established itself as a proactive player in global technology markets, through creating a strong, co-ordinated research base with good links to industry. Where is the UK positioned??

The USA

Background

The National Nanotechnology Initiative.
In January 2000, The Clinton Administration announced the National Nanotechnology Initiative (NNI). The NNI provides funding to a number of government departments for nanotechnology research and draws together the research under the following topics:

- Phenomena at the nanoscale
- Atomic and molecular scale structures and their manipulation
- Functional nanostructures
- Instrumentation for characterising single molecular and clusters
- Understanding the cell and modern biology
- Assembling and connecting at the nanoscale

To this end $500 million was sought from congress to fund multidisciplinary projects across several departments. (In the end, $422 was agreed for the fiscal year 2000-2001, and this year, the budget has risen to $485 million).

In August 2000, the Nanoscale Science Engineering and Technology (NSET) sub committee of the National Science and Technology Council was established, chaired by Dr Mihail Roco. Its goals were to implement NNI, facilitate interagency collaboration for nanoscale R&D including NNI, to develop a vision for nanotechnology and provide a framework for establishing federal R&D priorities and budget. Other participants in NSET included the main funding agencies – DOE, NASA, NIH and so on. The expected outcomes that are developing the field of nanotechnology, creating collaborations, prioritising R&D themes, providing a balanced infrastructure, initiating budget requests, and providing a framework for investment.

The main elements of the focus of NNI in the fiscal year 2001, (see nano.gov) are
Fundamental research – providing sustained support to individuals and small groups doing innovative research
Grand challenges* - funding for research on major long term objectives
Centres and Networks of Excellence – support for interdisciplinary research, networking and industry partnerships
Research Infrastructure – including metrology, instrumentation, modelling / simulation and user facilities
Societal Implications and Workforce Education and Training – aimed at creating a new generation of skilled workers; and examining the impact of nanotechnology on society (legal, ethical, social and economic)

*The list of **Grand Challenge** topics is an impressive one; with few obvious omissions:
- Nanostructured materials ‘by design’ – stronger, lighter, harder, self repairing and safer
- Nanoelectronics, optoelectronics and magnetics
- Advanced healthcare, therapeutics and diagnostics
- Nanoscale processes for environmental improvement
- Efficient energy conversion and storage
- Microcraft space exploration and industrialisation
- Bio-nanosensors for communicable disease and biological threat detection
- Applications to economical and safe transport
- National security

NSF funding has been instrumental in establishing multidisciplinary research centres (e.g. at Cornell) and, along with other agencies, in supporting the more ‘off-the-wall’ projects (described as ‘novel phenomena’), for example, three dimensional architecture for nanoscale electronic circuits which combine nano-bio-IT (a University of Minnesota project), a favoured combination for the vision of the future of technology as seen by the US; and the exploratory work on phages as the basis for massively parallel manufacturing, undertaken by Professor Ed Goldberg at Tufts. Prior to NNI it is unlikely this highly speculative work would have been supported.

Science and Technology Centres

NSF also provides funds for science and technology centres, whose aims are to support innovation by integrating research education and knowledge transfer; build an infrastructure that cuts across disciplines, conducts world-class research through partnerships, and links new knowledge meaningfully to society. This was the brief for the application by Cornell and its 3 partners to create a Nanobiotechnology Centre (NBTC). It was one of five such Centres funded in 2000. The Centre is specifically addressing the area of nanotechnology at the 'confluence' of nano / microfabrication and biosystems. It is highly multidisciplinary, and is viewed as having the potential for far-reaching impact. Cornell made a strong impression on the Mission team, as it really seemed to be working, and truly making an impact. The quality of projects, their themes, the insistence that their main product was people, and the work in the wider community was no less than enviable, and due in great part to the vision, determination and personality of its leader, Harold Craighead.

National Nanofabrication Users Network

The NSF has funded a network of 5 Centres across the US since 1994 to meet their objective of putting in place an infrastructure for nanotechnology development. These nodes are at Cornell, Howard, Penn State, Stanford and UCSB. Each node has general and specific specialisms.
Cornell: general micro and nanofabrication, and electron beam lithography facilities
Howard: wide band semiconductors
PSU: General micro and nanofabrication; and nanofabrication in novel materials
SNF: General micro and nanofabrication; Si devices and technology
UCSB: Dry etching and III-V semiconductor structures.
The National Nanofabrication Network facilities have to meet demanding requirements for their funding. They all have state-of-the-art equipment and process expertise; the equipment needs to be flexible enough to encompass several applications e.g. in wafer, process and materials technologies. Each facility has to accept that there are experimental risks associated with the multitude of processes and materials activities, and behave accordingly (that is why the CNF allocates 20% of staff time to safety!!). They have to be able to rapidly adapt and develop new techniques, and be open to new ideas. The management structure has to be able to coordinate and integrate many complex processes and tools.

The NSF provides approximately 36% of the funds required, which principally support staff costs, user fees etc fund the remaining costs. According to NNUN statistics, the largest percentage of growth in the use of the facilities is in the area of biology and chemistry, especially the latter.

According to NNUN publicity, having linked, specific facilities distributed around the country are an effective use of resources, and is a successful way of executing nanostructured science and engineering research. The variety of demands of nanoscience and technology make networked Universities (with critical mass) the appropriate location for facilities. Research in nanostructures also requires coordination of multiple fabrication, synthesis and characterisation tools, (and the complexity of execution is increasing at a faster rate with projects) which can only be met by this kind of infrastructure.
NNUN also meets the need for expensive working equipment - the cost of instrumentation has increased rapidly, and new users at nano-dimensions have increased capital needs, and needs for expensive expert staff with strong research skills, whose salaries need to be competitive with industry.

Conclusions from the USA

The US IS also serious about nanotechnology, and like Germany, has an infrastructure in place prior to the NN funding. Seed funding has been available since 1991 for the Synthesis and Processing of Nanoparticles; since 1994 for the National Nanofabrication Users Network, and since 1995 for projects on Nanoscale Instrumentation. Larger investments have been made in FY 1998 in Functional Nanostructures, Biosystems at the Nanoscale (FY 1999), and Nanoscale Modelling and Simulation (FY 2000). So NNI was not a bolt from the blue, but provided funds to draw together existing strands to work in a concerted way in order to find answers to some fundamental questions.

Meeting the Mission Objectives

Although there are variations in approach between Germany and the US as discussed above, in the context of this Mission, there are some general conclusions to be made:

1. Big business IS aware of nanotechnology, but doesn't tend to have much expertise in house. Companies are taking a variety of different routes to gaining access to the technology, mainly as an insurance against the day when they will need it.

2. Important funding is mainly from government sources, who are very committed, and there is a considerable emphasis on blue sky research.

3. Nanotechnology is already being exploited in new materials, and future opportunities exist in diagnostic and analytical techniques, and the commercialisation of the 'new' sciences e.g. genomics, proteomics and pharmacogenetics; i.e. at the interface between physical and biological sciences.

4. Nanotechnology is being applied in the controlled manufacture of nanoparticles for many applications including drug delivery, incorporation in paints pigments and coatings, suncreams and cosmetics.

5. Major large companies involved in nanotechnology are seeing commercial returns in materials, pigments, pharma and cosmeceuticals. Smaller companies are involved in exploiting niche market opportunities in labelling (quantum dots). Mainly companies see nanotechnology as a progression in the miniaturisation of existing technology e.g. in sensors, diagnostic and analytical techniques.

6. *Manufacturing* at the nanoscale is still not really happening, except in the production of nanoparticles, which are incorporated into other products; and peripheral technologies, like the dispensing of nanolitre samples and making thin films. Massively parallel manufacturing is still an unresolved problem.

7. The perceived benefits are in a nutshell – improved functionality for less cost.

8. New applications relate to high throughput screening for drug discovery in relation to genotype and phenotype-friendly drugs.

9. The overall strategy in the States does differ fundamentally from that in Germany. In the US, the strategy is two fold – to create an infrastructure which will enable people to do the work; and support fundamental, innovative interdisciplinary research. In Germany, the strategy to research those technologies that will feed into industry, as well as funding some speculative technology for the future. In summary, US funding is mostly for blue-skies research; and German funding is mostly for supporting industry in the future. The drive to commercialisation in Germany has moved up the agenda, as essential for the economy and jobs. In the US there is less pressure from the funding bodies, but venture capitalists will invest in concepts at a very early stage.

10. Problems include lack of trained staff, lack of science graduates and undergraduates, a shortage of science teachers in schools, and a possible backlash by the public against nanotechnology.

General Conclusions

The consequence of the UK not having a microsystems infrastructure is we a harder race to run if we intend to capitalise on the early applications of nanotechnology. However, the end game is a long one, and there is still time to implement a strategy that will enable the UK economy to participate in and benefit from this technological revolution:

This strategy needs

- A small team of visionary experts to advise the Government
- Clear identification of goals – Grand Challenges
- New funding for quality research - both for individuals and groups - in support of these goals
- Funding to support necessary infrastructure requirements
- Encouragement for commercial involvement in research projects
- ‘Joined up’ research and development policy
- Assurance of quality education in science and technology at secondary and tertiary levels

Nanotechnology has already seen commercialisation in *new materials*; for which it is predicted there are almost unlimited opportunities for innovation. In the near future, nanotechnology is seen as the means of achieving the goal of high throughput, low volume diagnostic and analytical techniques, as a continuum of the miniaturisation of today’s microtechnologies.

As evidence of a growing commitment to nanotechnology, the research councils (EPSRC, BBSRC, MRC and the MOD) and the DTI, have now jointly called for proposals to create two or three Interdisciplinary Research Centres in Nanotechnology with total funding of approximately £9 million funding earmarked over 6 years. These Centres promise great things, but are only a beginning.

Small Company Perspective

Summary

SME’s are essential components in the transfer and commercialisation of nanotechnology from the research base. Both the US and Germany have developed ‘nanotechnology networks’ which are viewed as essential in providing a connection between academic institutes, SME’s and larger companies. Regional technology institutes or networks (some specifically targeting nanotechnology) have been developed in the US to foster the growth and success of SME’s by providing expertise in technology, finance and business.

SME Formation

Small and medium sized enterprises (SME’s) are essential components in the transfer and commercialisation of nanotechnology from the research base. Universities and research institutes in both the US and Germany are increasingly alive to the opportunities of technology licensing and the formation of spin-out companies. In the US, spin-out companies benefit universities for several reasons including

- providing direction for future research,
- greater control over discoveries
- increased income to professors, departments and universities.

In addition the ability to show the commercial applications of research was necessary to win federal funding. However, like in the UK, universities differ dramatically in technology transfer and spin-out activities. For example, comparing Cornell and MIT, the latter has been more successful partly due to lower barriers for technology licensing and an environment promoting entrepreneurship. In Germany, a new entrepreneurial culture amongst researchers is being encouraged, but there is still an anxiety that the movement of new technology into the market place is not happening quickly enough. In the last few years there has been a radical change in the philosophy towards spin-outs from Universities and research centres. They have become more open towards commercialisation activities, and less strict in terms of patent rights Assistance is being provided to scientists with commercial ideas (in the form of subsidised facilities and support for patents, and less demands for IP ownership on behalf of the Institutions concerned), and this has resulted in increasing collaborations between academic groups and industry.

In addition, Germany is exploring the creation of SME's from the novel Caesar institute in Bonn, where research is firmly targeted at short-term commercial applications, with nanotechnology being identified as a major research focus. The goal of each research project is to create marketable innovations that lead to the establishment of spin-out companies. Substantial support is provided to the formation of these spin-out companies.

2. SME's & Nanotechnology Networks

Both the US and Germany have funded nanotechnology networks which are viewed as essential in providing a connection between academic institutes, SME's and larger companies. These networks also promote the creation and development of SME's. In the US there are networks that are coordinated at the state level, although there does not appear to be any significant communication between these networks (eg 'Ben Franklin and Partners' and 'Virginia's Center for Innovative Technology'). Ben Franklin and Partners is an independent non-profit economic development organization for the southeastern Pennsylvania region, whose are:

- to foster the growth and success of the technology sector as a basis for new economic growth
- provide capital and expertise in technology, finance and business to help entrepreneurs foster dynamic relationships among companies, institutional and private investors, research institutions and the university community.
- design and develop community and regional initiatives that accelerate the technological evolution of the region.

Ben Franklin has a program specifically targeting nanotechnology ('The Nanotechnology Institute') formed from collaboration between local universities, industry and government. The primary focus of the Institute is the transfer of discoveries and intellectual knowledge from universities to industrial partners and the promotion of rapid application and commercialization. Funding was provided by a three-year $10.5 million grant from Pennsylvania State.

In addition to these regional initiatives, the US has a federally funded National Nanofabrication Users Network which comprises 5 centres around the US housing state-of-the-art nanofabrication facilities. Academic institutes and industry have access to the facilities at a relatively low cost, particularly appealing for the SME. In comparison, Germany has a more coordinated nanotechnology network across the country with the creation of six Competence Networks in 1999 operating in the five key areas of nanoscience, as identified by the German government as of strategic importance. Each Competence Network is comprised of university institutes, research centers and companies (large, medium and small). These networks provide particular benefit to SME's in terms of access to know-how and making contact with potential customers.

3. SME Funding

In the US, the State level technology networks act as a source of capital for the creation and development of SME's. At a federal level the Small Business Innovation Research (SBIR) program exists for SME creation and development. Spin-out companies encountered from Tufts and Cornell University had all used this program for funding and was generally perceived to be a success. The basic purpose of the SBIR was to strengthen the role of small innovative enterprises in federally-funded research and development and thus help the US develop a stronger base for technical innovation. Federal agency funds are used to support an annual competition for Phase I awards of up to $100,000 each for about 6 months to explore the feasibility of innovative concepts. Phase II is the principal research or R&D effort, and the awards are up to $750,000 over a two-year period. In Phase III, it is intended that non-Federal capital be used by the small business concern to pursue commercial applications of the R&D. Also under Phase III, Federal agencies may award non-SBIR funded follow-on grants or contracts for products or processes that meet the mission needs of those agencies, or for further research or R&D.

In Germany, funding for new technology SME's was perceived to be somewhat more difficult. The exceptions were for those companies who were willing to relocate less developed areas of the country and received financial incentives to do so. In general, although receiving more moral encouragement, or early support in the case of University spin-outs, small, new technology businesses needed to find ventures capitalists, EU money or investment from large companies interested in their products.

Conclusions

Germany is fostering a culture of support for commercialising technologies from the research base, but there is still an anxiety that it is not happening quickly enough. Both Germany and the US have networks, the German networks are networks of competence aimed at helping business in a particular discipline; in the USA the networks are localised at State level in the main, and offer more general help to business. Regarding funding, the SBIR mechanism has been exceptionally useful in funding spin-offs in the USA.

Large Company Perspective

Summary

Large companies are in the main looking for a way of becoming involved in nanotechnology. Their product base is wide ranging, and the possibilities seem endless. The questions they ask are - Where do we invest? Which are the winning technologies? How do we spot them?

In Germany, the arm's length approach has been favoured, as a means of ensuring access to a new technology without diverting resources from the core business, or taking the development risks in-house.

Examples include the creation of a joint venture between a large company and a University as a means of gaining access to strategic nanotechnologies. The large company partner benefits directly from any new technology that is relevant to its business, and indirectly by having a share in others that are not. The University and its researchers also benefit, having shares in the company. Another interesting model that allows large companies to keep abreast of nanotechnology is by investing in an innovative company working in a useful technological field. A not dissimilar model, but in reverse, and with the same objectives, is where a large company has spun out a new high tech start-up, which extends the skills and know-how of the parent into a new market.

Exceptions to the arm's length approach are cosmeceutical manufacturers and their suppliers who seem to be leading the field in embracing nanotechnology. Cosmeceutical companies see it as a way of delivering clear benefits to their customers, through control of colour, texture, perception and the eventual possible delivery of holistic cosmetics (inclusion of vitamins etc). Suppliers recognise that the ability to manufacture nanoparticles of different shapes, sizes and with novel coatings and surface features is becoming increasingly critical – not only in cosmetics, but also for incorporation in paints, pigments, coatings and pharmaceuticals.

In the USA, the involvement of large companies in nanotechnology is perhaps less clear, simply because of the fact the Mission went to the East coast, and the companies tend to be in the West.

Some insights were gleaned, however. For example, large companies are happy to put money into nanotechnology research centres such as Cornell, in order to get technology out through a continuous flow of well-qualified people back into industry. The motivation is that they can access the right people at the right time when they need to, i.e. when the new technology arrives. Furthermore, there does not appear to be a significant number of people within big companies with expertise in nanotechnology, perhaps apart from the electronics and materials sectors.

In certain sectors, e.g. pharmaceuticals, the risk of becoming involved in a new technology in-house is minimised by buying the services of smaller more specialist companies letting them take the risks, by having to competitively develop new technologies, in the knowledge that they may be 'swept out of the water' when a new, disruptive technology comes along.

Large Companies and Nanotechnology in Germany

In Germany, large companies appreciate that nanotechnology offers the promise of new products and the opportunity to make existing products better. However, there are so many avenues to pursue, it is difficult to know which to take, and where the investment should be placed. One kind of approach has been that of Henkel. Henkel is a company that could perhaps be compared to Unilever in its product base. They have created a joint venture with a University in Darmstadt – SusTech. This is a relatively low-risk, highly visionary strategy which allows Henkel access to a raft of new technologies, with clear commercial end points, as they are developed. By this means, Henkel can benefit financially from the commercialisation of any technologies they do not want, and the use of any that they do. Furthermore, in setting up this kind of venture there has been leverage from obtaining financial support for some of the research work from the German Research ministry.

Another large company model relates to microParts, a company which specialises in innovative microsystems technologies. Both Steag and Degussa are major investors in this highly successful and innovative company, viewing it as an entrée into the world of microengineering that may be better achieved outwith their own companies. Perhaps with similar objective to the investment by Steag and Degussa in microParts, Jenoptik has supported the spin-out of Mildendo which specialises in microfluidic solutions, based on polymer technology. In this way, Jenoptik benefits from extending its skills and know-how into a new market.

In Germany there has been an impressive and detailed approach to creating an infrastructure across the spectrum of pure research, applications-oriented research and research within Universities, all of which produce not only good students for research in industry.

Large Companies and Nanotechnology in the USA.

In the USA, the large company response to nanotechnology and their relationship the Centers of Excellence, such as Cornell, is not entirely clear (as a result of the geographic focus of the Mission on the East Coast.). However, it is obvious that both Government and industry are pushing money into academic research, with the aim of ensuring there is a ready outflow of qualified individuals into industry. Cornell remarked tellingly that their most important output was people. The lesson is that the big companies, in spite of what they are doing in house, are actively investing money in encouraging others to create the basic elements that they might need *in order to develop the technology later*. A kind of insurance. In general it could be said that large companies are feeling their way, and have limited exposure to nanotechnology at present.

ICI and Unilever are probably in a similar situation as US corporations, insofar as they
see ways of nanotechnology impacting on future business
don't have enough knowledgeable and experienced people
need to find out more by placing contracts with key centres
will second people into centres to get expertise and bring it back

In the USA, there is more real awareness of nanotechnology in some states than others; but it is clear that no-one wants to be left off the bandwagon. Individual states support nanotechnology, thinking of it in terms of the electronics or e-business booms, as a means of bringing employment into small companies. There is a sense of paranoia, both nationally and at State level to be in the thick of the action. At state level, funding is available, sometimes without much real thought to benefits or strategy, at national level nanotechnology a key watch area for the USA overseas.

Cornell's NanoBiotechnology Center was one of the most impressive the team visited, with a wide range of activities, good people, quality research, making real efforts at creating a multidisciplinary approach, committed to outreach, and with an invaluable link to the Nanofabrication Facility and last but not least, having the leadership of Harold Craighead'.

Of the companies seen, it must be said most were not truly 'nano' but saw nanotechnology as an evolutionary step to more efficient and cost effective products, providing more functionality and reliability. Because of the need to satisfy shareholders, most companies spend money on the 'D' rather than on speculative 'R' of R&D. But like many companies today, because science is moving into hitherto unimaginable realms, nanotechnology is seen as a threatening technology, driving possible disruptive technological innovations.

DARPA had some relevance for big business, as it funds applications oriented research; mainly with big companies, and as 'small' companies by definition can't be in nano'. But the problem with DARPA funded projects is that good ideas may sit on the shelf if they are deemed to have national security implications.

Conclusions from the Large Company Perspective.

Universities in Germany plus the Max Planck Institutes plus the Fraunhofers work as a joined up system to the benefit of German companies and the advancement of nanotechnology. In the US, science centres such as Cornell NanoBiotechnology Centre provide trained people for industry; and the infrastructure such as the National Nanofabrication Network combined with the Materials Research Centers which focus on nanotechnology, enable both the development of people and technology, for large companies to pick up later.

Academic Perspective - Physical Sciences

Summary

It was very obvious from the missions was that both the USA and Germany have significant and long term commitments to the creation and support of the infrastructure required for the development of physical structures in micro and nanotechnology.

What both countries have understood is that this expertise is not available off the shelf and takes time to build, and so long term commitment is essential. As with most high technology activities it takes significantly even more time and resource to reactivate a technological capability (like nanofabrication) once staff have moved on and equipment has ceased to be used. There is a deep acceptance in both the US and Germany that individuals with key technical expertise need to have a long term employment horizon to ensure continuity, in addition to being provided with the appropriate equipment and facilities so research goals can be met.

USA and Germany

Both countries have a created a strong research infrastructure in the key enabling areas of microsystems (MEMS), microfabrication associated with the IC (integrated circuit) industry and packaging technologies. In Germany the Max Planck Institutes provide a vehicle for long term investment in basic nanoscience, with the Fraunhofers being funded to support more applied developments. The long term funding horizons of both these organisations to develop micro / nanotechnology R&D, has resulted in a strong foundation for the exploitation of the science and technology of fabrication.

In contrast the UK support in these key areas has been patchy and consequently the UK is lagging behind. This is certainly the case in microsystems technology where sustained funding has not been applied, resulting in a fragmented community. There is every danger of this repeating itself with nanotechnology.

One message that came through loud and clear was that, regardless of the focus of any UK nanotechnology initiative, it is essential that the supporting infrastructure includes a strong and integrated micro / nanofabrication technical capability.

Another essential component of the nanotechnology initiatives in both Germany and the USA was the support of training in nanotechnology related to the physical sciences and engineering. This was seen as being essential for fostering the development of nanotechnology and in particular interdisciplinary support so that that expertise in structure fabrication can also be applied in the non-physical science areas.

Conclusions
To succeed in nanotechnology the UK needs longer term funding for research, infrastructure funding to support a strong and integrated micro / nanofabrication capability, and support for the cross-disciplinary education and training of scientists.

NANOTECHNOLOGY MISSION TO GERMANY

4-9 March 2001

MAX PLANCK INSTITUTE OF COLLOIDS AND INTERFACES

http://www.mpikg-golm.mpg.de/gf/

Prof Dr Markus Antonietti and staff

The objective of the visit to this Max Planck Institute was to determine how nanotechnology is perceived within a fundamental research programme into the properties of colloids and interfaces – areas where chemistry and physics meets biology. The opportunities for incorporating nanoscale science and technology into these research programmes seemed highly relevant to explore on this Mission. Professor Antonietti sits on Gemany's "foresight" committee on nanotechnology.

Background:
Within the Max Planck Society for the Advancement of the Sciences there are 81 independent institutes. Max Planck Institutes focus on new, fundamental research that cannot be accommodated easily within the University environment due to its multidisciplinary nature or requirement for staff and / or facilities. Normally 95% of the funding is public (Federal Government and individual States). The budget in 2000 was about 2.3B DM. There are about 11,000 staff, of whom 3000 are scientists, and 6900 are doctoral candidates, post doctoral fellows and scholars from all over the world.
[See http://www.britishembassy.de – under "Research & Technology"]

The Max Planck Institute of Colloids and Interfaces is an outcome of reunification. It was founded in 1993 as one of the first Max Planck Institutes of Eastern Germany. It brought together the three former GDR institutes in polymer, organic and physical chemistry. The aim of the new Institute was to build a multidisciplinary research base that looked to the future, and bring in new blood from different backgrounds as well as integrating existing staff from both east and west. This has been successful despite the early difficulties of location, resolved in 1998 when the Institute moved to brand-new, purpose built laboratories in Potsdam. Present staff numbers are in excess of 250, with 100 permanent positions and 40 scientific staff. Younger members of staff view the Institute as being a fast-track for promotion to a University position.

Although it is the Institute's stated objective and desire to concentrate on fundamental research, it finds it increasingly difficult to maintain this. Some industrial co-operations exist, for example with L'Oreal, BASF and Roche, which together provides a surprising 40% of the funding of the Institute. There is pressure by industry to form more partnerships, as evidence of a growing industrial interest in the topics studied. The Institute has now reached a stage where it has to field off requests from industry in order to concentrate on its own pure research agenda. However, the commercial potential of research outcomes is not ignored, and several applications are currently in the process of being commercialised.

Research Activities

As discussed above, applications are not the ultimate goal though this often may be the motivation! In the Max Planck Institute at Golm, the overlying objective is to understand the structure of interfaces and their relation to dynamics and function.

Prof Dr Antonietti presented information on the background to the creation of the Max Planck Institute at Golm, its structure, and the funding regime and expectations of the funders, stating that “nano business in Germany has become a major commercial issue” with a DM15 bn market.

Presentations were also made by Group Leaders on specific topics deemed to be of interest to the Mission, including:
Dr David Gittens: nanoparticle chemistry, scale-up of nanoparticle production, quantum dots, phosphors, biolabelling, bioimaging, cell death, directed deposition, security products (see Nanosolutions GmbH), inks, catalysts (hetero and homogeneous)
Dr Helmut Cölfen: Biomimetic mineralisation and fractionating colloid analytics, filament growth forming neuron-like networks
Dr Katharina Landfester: Mini emulsion polymerisation; particle synthesis within micelles; nanocapsules
Dr Frank Caruso: Nanostructured interfaces and materials, encapsulationn strategies, self assembly and a spin out company, Capsulation Nanoscience AG.
Dr Roland Netz: Theoretical approaches to nanoscopic systems

Future research directions of the Institute will focus on:
1. Artificial Cells - with specific reference to membrane and interface functions
2. The theory of biomimetic systems
3. New concepts in colloid chemistry
4. Compartmentalization - biomimetic chaperone systems and nanocrystallinity

Collaborations

The structure of the research is that staff scientists lead small largely independent groups. Good interdisciplinary contacts exist between the various project groups in the Institute, and there are strong external links through joint projects with the four Berlin universities; the neutron reaction source at the Hahn-Meitner-Institute and the synchrotron radiation facility, BESSY. Recent collaborations include an EC-funded network on 'Nanocapsules as Biomimetic Cells' and a German-French collaboration on 'Complex Fluids from 2D to 3D'.

Nano and MPI-KG: There are particular benefits for developing <u>*any*</u> *leading edge research in the way the funding system operates for the Max Planck Institutes in general, as the Government provides the money, and accepts each MPI will set their own research agenda. There is no great pressure to find commercial partners. The trend in Germany is now towards funding for larger projects of 10m – 50 m DM. A serious problem is finding enough physics and chemistry students – currently they are recruiting from East Europe and China.*

CHARITÉ AT HUMBOLDT UNIVERSITY

http://www.charité.de

Dr Andreas Jordan

The visit to Charité, Europe's largest University Clinic, was particularly aimed at meeting Dr Andreas Jordan who has created a nanotechnology spin-out company to commercialise a medical application of magnetic nanoparticles. The objective was to determine Government support for new projects in general, and nanotechnology in particular, and the attitude of the University. Dr Jordan was particularly helpful to the mission as he leads a nanotechnology network, and is also a nanotechnology expert for the Government.

Background

Charité is the medical faculty and clinic of the Humboldt University, and is based at three sites – Virchow-Klinikum, Charité Mitte and Berlin Buch. The biomedical nanotechnology group has grown out of the Radiology Department in Virchow. Led by Dr Jordan, the group has recently developed a method of introducing colloidal dispersions of superparamagnetic biocompatible iron oxide nanoparticles into tumours. This work has led to the formation of two spin-off companies, MFH GmbH and MagForce Applications GmbH.

The application of an external magnetic field causes the magnetic particles to heat the surrounding tissues to 45 – 47 C. As a result some cancer cells die and liquidise. The magnetic particles are homogeneously distributed throughout the liquid containing the dead cancerous cells, which then extends further into the tumour. The magnetic field is reapplied and further regions of the tumour are treated. At the end of treatment, the necrotic fluid with the iron particles is degraded by the body's immune system.

The fact that these colloidally dispersed nanoparticles exhibited an extraordinary specific absorption rate may have implications for the effects of other nanoparticles under a variety of conditions that may cause them to exhibit both benign and non-benign outcomes.

The application of magnetic fluid hyperthermia to treating cancer is Dr Jordans' second commercial venture. He commented how the philosophy towards spin-outs in Germany has changed radically. Academic institutions are becoming less strict in terms of patent rights (before they insisted on owning the rights, but would not contribute to costs). They are providing assistance to scientists with commercial ideas, and are looking on collaborations between research groups and industry with increasing favour. Dr Jordan's own group received funding from German Cancer Aid, a private organisation; and his new company is receiving venture capital from several sources.

Dr Jordan also leads a nanochemistry network, one of the six within the network of Competence Centres as well as also being a nanotechnology research expert for the BMBF (the German research ministry). All German companies of note belong to these competence centres. His view was that the outputs of the networks may not be enormous, but running costs are low, and they do provide a focus for groups with similar objectives.

Dr. Jordan expressed concern that without careful management, public resistance to nanotechnology will develop as it has with genetics.

Nano and Charité: Nanotechnology has enabled the production of uniform nanoscale particles exhibiting unexpected biocompatibility and enhanced speed of uptake by cells.
Dr Jordan's final thought on nanotechnology policy was that simple messages could unify the field.

BST Bio Sensor Technologie GmbH
email: bst@bbtt.com

Dr Dorothea Pfeiffer and staff; Dr Frank Bier, Molecular Bioanalytics Group, Fraunhofer Institute for Biomedical Engineering, Bergholz-Rehbrücke

The visit to BST was made to determine the extent to which nanotechnology is being utilised currently, or will be utilised in the future by a commercial sensor company. The Mission was interested in learning the kind of support offered by the government for smaller technology companies who wish to adopt nanotechnology.

BST Bio Sensor Technologie GmbH was founded in 1981 in Berlin by four members of the former biosensorics group within the Institute of Analytical Biochemistry, in the University of Potsdam. It was part funded by Government, (who provided support in the early stages) and part by private finance for the development of a glucose biosensor.

BST now has 20 years experience in the development, optimisation and final production of biosensors, and holds more than 80 patents. Cooperation with industry goes back to the late seventies and resulted in the first biosensor based glucose analyser produced in Europe in 1982. Their core technology is the immobilisation of glucose oxidase onto polymer supports to produce reproducible protein layers. Several products are market leaders in Germany, and include glucose, lactate, uric acid, lactose, sucrose, maltose, glutamate, lysine, ascorbic acid and malic acid sensors. Research is now focusing on

- Hydrogen peroxide sensors
- Superoxide sensors for medical, cosmetic and food applications
- Hormone (for steroid detection) and optical chips, with applications in medical diagnostics

The company's main areas of operation are in the

- production of reusable biosensors
- development of biosensors through own and contract research for medical diagnosis, the food industry, fermentation control, and environmental monitoring.
- design and manufacture of laboratory consumables
- education and seminars (consultancy, teaching, courses etc).

Recently, funding from the European Space Agency has directed their work towards miniaturisation, giving BST an impetus to explore the science behind their technology. BST now looking to link with companies having complementary skills, e.g. in microfluidics; and develop further alliances e.g. with instrument makers, and are setting up their own (glucose analysis) instrument company in Dresden, to take advantage of substantial inward investment benefits. Regarding funding, BST have experienced some difficulties in obtaining money from Government, and the feeling is that allocations are politically motivated.

Nano and BST: The future development of sensors is seen to lie in the integration of nanotechnologies with existing techniques used e.g. in the immobilisation of enzymes for benefits of scale, functionality and efficiency.

Beiersdorf AG
http://www.beiersdorf.de

Dr Wepf, Head of Analytical Microscopy, and staff

Beiersdorf is a relatively large organisation (15,800 employees worldwide) with a spread of materials and pharmaceutical related products where one might expect to see early applications of nanotechnology. The pragmatic approach by the company to nanotechnology was fairly representative of others we visited. However, some interesting points were made regarding where the line might be drawn in future between a cosmetic and a pharmaceutical; and the implications of genomics and proteomics for future 'interface' products.

Beiersdorf was established in Hamburg in 1882. Today, the company operates internationally, producing market-leading branded products in the areas of cosmetics, personal care, wound care, and adhesive tapes. The most important strategic goal still remains maintenance of the orientation of all corporate divisions towards these historical core areas of expertise.

There are three divisions:

- The Cosmed Division: Cosmetics and body care.
- The Medical Division: Concentrating on the treatment of diseased and damaged skin, and products for orthopaedics / phlebology and dermatology.
- The tesa Division: Adhesive technology for three main applications: fastening, masking and packaging.

Some Beiersdorf brands recognised world-wide include:

Cosmed Division: Nivea, Labello, Atrixo, Juvena,
Medical Division: Hansaplast, Elastoplast, Leukoplast,
tesa Division: tesa Film, tesa Poster-Strips, tesa Power-Strips, tesa Fix

Key areas of product development are still in the three traditional core competence areas described above. The innovation rate, i.e. the share of sales due to products launched in the last five years, is over 30%. Group spending on research and development increased faster than sales with a rise of 10.5% to DM 155 million last year.

A trend-setting project that was discussed related to novel data storage on rolls of polymer films. Known for short as "tesa-ROM", this invention has generated considerable interest and publicity. Laser beams are used to write data onto, and read from, a classic tesa Multifilm. High storage density is possible, opening up opportunities for developing an entirely new compact data storage medium. Already a number of patents have been applied for,

Beiersdorf listed areas where nanotechnology has important implications for them. In their cosmeceutical division, nanoanalytics, ways of determining the ultrastructure of the skin, use of nanoparticles in sun protection and understanding nanoscale effects in skin treatments. In adhesives, nanoscale effects are critical for several reasons: phase separation begins at the nanoscale; the phases are identified by nanomechanical effects and micromechanics correlates with macroscopic effects.

The general view is that the more you intimately understand the effects of the products, the better the R&D, the smarter and more sustainable the product.

The Mission team also visited the laboratory to investigate further the development of 'cosmeceuticals'. Discussions centred on the eventual inclusion of active therapeutic agents giving future products a competitive advantage. It may be that future cosmeceutical preparations will have be subject to the same stringent regulations as 'conventional' drugs, and new products may be developed based on the individual's genotype, on order to minimise side effects. However, a stumbling block may be that it is not only the genotype which affects the response of an individual to chemicals entering the body, but also the phenotype.

Nano and Cosmeceuticals. As nanotechnology is seen as the tool for commercialising the outcome of the human genome project, a challenge therefore would be the tailoring of the next generation of 'Quality of Life' products to an individual's genotype <u>and</u> possibly, phenotype.

EVOTEC BioSystems AG, Hamburg.
http://www.evotec.de

Dr Timm-H Jessen

As with BST, Evotec was selected as a useful company to visit to determine the extent to which nanotechnology is being utilised currently, or may be utilised in the future by a life sciences company.

Evotec, founded in December 1993, is a growing biotechnology company serving the life sciences industry, with a portfolio of services in the preclinical field. It is number 2 in Germany and since the merger with Oxford Asymmetry International last year, has become no 5 in Europe. The new company Evotec AOI has a staff of 600.

Evotec has developed a broad proprietary platform of technologies designed to dramatically increase the efficiency of the drug discovery process, reducing the time involved in preclinical drug development (which can take up to 10 years), thus reducing cost. Its core strength is in the fluorescent tagging of biomolecules. By combining the information content from its biological test systems with an ultrafast screening technology, the company has achieved a technology leadership in the area of drug discovery. It also provides novel pharmaceutical precursor products.

Evotec is currently developing technology in conjunction with Novartis, SmithKline Beecham and Pfizer, amongst others. The company is in the process of obtaining rights to proprietary drug discovery targets, and screens libraries against those targets for internal development, developing drug candidates to a point where they will be sold or licensed to third parties. A subsidiary company, EVOTEC NeuroSciences GmbH conducts research on proprietary targets and develops lead compounds for neurodegenerative diseases.

EVOTEC has developed a miniaturized automated platform for economical high-efficiency drug discovery, not only applicable to primary screening, but also to downstream of discovery in early ADME (Absorption, Distribution, Metabolism and Excretion) and even toxicity testing.

The Mission team was also shown a technique that Evotec have developed with the Humboldt University which uses an AC electric field gradient to trap individual cells in a 'cage'. This cell 'fixing' allows individual cells to be profiled. Throughput is currently 100 cells / hour.

There was a discussion regarding the recent sea change in attitude by the German Government towards start-ups. In 1990 Evotec was funded by business angels, but recently the Government has made public money available. There is also increasing flexibility within the research institutes, for example, the Max Planck Institute transferred patent rights in return for equity.

Nano and Evotec. With regard to nanotechnology, Evotec agree that it offers economic benefits from sample miniaturisation, faster throughput a reduction in reagent requirements and the opportunity to develop desktop assaying. There are problems that need to be solved, including decreased signal to noise, that come with increased miniaturisation, and the challenges of detection. There is a drive to complexity in all fronts, and the adoption of nanotechnology is the only way it can be achieved economically. They see the impact of nanotechnology particularly in drug formulation, biosensors, and instrumentation.

NanoSolutions
http://www.nano-solutions.de

Dr Stephan Haubold

NanoSolutions was of interest to the Mission as an example of recent start up company; considered by the Max Planck Institute at Golm, who work with NanoSolutions, as an interesting case study of small nanocompany development in Germany. Their early success, they claim, is due to close cooperation with a strong industrial partner.

NanoSolutions was founded in June 2000 because of a customer (Bayer AG) who was interested in the commercial development of a biolabel based on phosphors. The company was spun out of the Institute of Physical Chemistry at the University of Hamburg based on the expertise generated by Prof Horst Weller who has been researching nanoparticle synthesis and their physical properties for the past 15 years. Prof Weller is the Institute director and leads a team of approximately 25 scientists.

The managing director, Dr Stephan Haubold, is a former PhD student of Prof Weller. The other owners of the company are Dr Markus Haase, who invented the nanophosphor synthesis and Armin Geibel, a business angel. At the present time NanoSolutions has 4 employees and by the end of the year predicts sales of €800,000. Since formation the company has filed 3 patents and will be moving into its own premises in May 2001, having used the University's premises in the initial start-up phase. The company has secured VC funding and plans to have 15 employees by the end of 2001.

Its present focus is the production of nanophosphors which fluoresce under excitation with UV-C light. The material can be suspended in nearly any liquid and does not scatter light. Possible applications include biolabels and security labels for machines, money, stamps etc. This technology involves growing the nanoparticles in solution which results in diameters of 5-7nm with a variation of 15-20%. They claim their technology is superior to that of Q-Dots Inc. (who have tied up the world market for bio applications of quantum dots), as they are non-toxic, being inert, and capable of surviving temperatures of 1200°C. At the present time they are able to synthesise 10gm of material in a single batch, which takes 24 hours. Scale up of this will be essential for the production of commercial volumes.

The University was very helpful in the initial phase of the company giving it access to facilities on extremely reasonable terms. Once the company moves to its new premises they will still use the University TEM facilities and will maintain close links with the Institute through Prof Weller. Although significant support is available to locate new companies in the East of the country, the company did not take up this option in order to maintain its close link with the Institute and the perceived difficulty of persuading graduates to move to the region. They also decided not to seek funding via BMBF projects, preferring the venture capital route. The business model is based on partnerships with companies who have potential applications, which provides NanoSolutions with cashflow. Dr. Haubold commented that although VCs in Germany are aware of, and responsive to, nanotechnology, the fact that the VCs' "nanotechnology experts" were essentially knowledgeable only about microelectronics presented some difficulties.

NanoSolutions see 'biolabel' opportunities as being 3-5 years away and are developing biolinking technology whilst in the shorter term concentrating on current market opportunities in security applications.

NanoSolutions', one of the few 'real' nanotechnology company, has been supported by the University of Hamburg in its early critical stages of development. The technology has several applications, and it will be interesting to watch the future growth of the business.

STEAG microParts GmbH, Dortmund
http://www.microparts.de

Dr Holger Bartos; Dr Stefan Kreutzberger

microParts is essentially a microsystems / microengineering company, mainly working on client-initiated projects. It has an excellent reputation for innovation, and has been consistently expanding over the last few years. The objective of the visit was to glean some understanding of why the company is so successful, and determine if and how they envisage embracing nanotechnology in the future.

microParts, founded in 1990, is a company focused on the development of microstructured plastic disposable products. Its main shareholders are STEAG and Degussa. Its original development was enabled by LIGA Technology at the Nuclear Research Centre of Karlsruhe in Germany. The three steps of LIGA - deep etch lithography by synchrotron radiation, electroforming, and micromoulding, made it possible for the first time to reproduce structures with micrometre dimensions. After a careful analysis of the potential of this technology, a consortium of five companies founded microParts GmbH in 1990. In 1994, microParts moved from Karlsruhe into new facilities in the 'Centre of Microstructure Technology' in Dortmund, to take advantage of an inward investment grant. Dortmund set its sights clearly on IT and microstructuring. MicroParts was one of the first microstructuring companies to establish in the region, which is now one of Europe's leading microtechnology clusters

In 1998 STEAG Electronic Systems AG became microParts major shareholder. In the following three years, the turnover of 30 million DM has been doubled. Since 1994 until today, the number of employees has grown from 40 to approximately 170, and is increasing.

microParts develops, manufactures and markets mainly medical microproducts for minimally- and non-invasive diagnostics, analysis and therapy for other companies. Products supply novel portable solutions to diagnostic and treatment methods. The interface between the microstructures and the macroscopic environment is a critical feature of these products and is where microParts has particular skills. Additional expertise relates to taking a product from the idea to high volume production.

In the early days, microParts produced a portfolio of products to demonstrate their competence covering a number of markets with emphasis on automotive. Eventually persistence paid off, and Boehringer-Ingelheim financially supported the development of their first important product, a mechanically actuated inhaler. Since then, microParts has gone from strength to strength. Their experience has been that pharma companies are more likely than any other sector (telecomms, automotive etc) to invest in product development and to work "in partnership", so the majority of microParts customers reside within that sector.

Main products groups are in:
Microfluidics. e.g. channel-/ nozzle plates for ink-jet printing and capillary structures for medical, pharmaceutical and environmental analysis; **Microoptics.** eg VIS- and NIR-microspectrometers for colour, medical and environmental analysis and **Advanced Drug Delivery Systems**

MicroParts see the advantages of miniaturisation in

- Reduced reaction times
- Reduced sample volume
- Reduced consumption of chemicals
- Parallel processing of many samples
- Automatic sample processing on chip
- Integration of functions like fluid propulsion, splitting, dosing or mixing

The team at microParts presented information on their Lilliput chip (a 96 well titre plate), produced in collaboration with Merlin Diagnostics. It is a novel automated instrument for bacteria identification and antibiotic susceptibility tests, which employs a capillary filling technique.

Another product of microParts is a bilirubin detector for non-invasive diagnosis of newborn infant jaundice developed together with SpectRX. The core product is a novel microspectrometer for cell growth measurement that microParts manufacture themselves. microParts have also developed a novel nucleic acid hybridisation platform for Exiqon's patented anthraquinone based method of photochemical covalent coupling of biomolecules to polymers.

In general, microstructured IVD disposables requirements are

- Low cost, large scale fabrication
- Produced in a size range from stamp to credit card
- Simple interface between disposable and instrument
- Integrated functions
- Specific surface properties, e.g. blood wetting
- Of application compatible materials
- Precisely sealed cavities

Microparts expertise is very strong in a range of techniques including

- the fabrication of microstructures from polymers;
- 3-D UV lithography;
- laser machining of microstructures,
- mechanical micromachining
- hydrophilisation of plastic surfaces (wetting behaviour)

MicroParts considers its links with the City of Dortmund, the University and the Technology Centre to be of primary importance in its development.

Nano and microParts. microParts envisage that the future lies in combining nano with micro. Nanotechnology can add functionality (e.g. biomolecules on plastic surfaces). Critical to miniaturisation (and there are lessons herein for the adoption of nanotechnology) is the interface with the macro world, replication, surface modifications, and assembly techniques, including sealing. They stress the importance of being product driven, much of the technology available is "too early for market".

Relab AG, Recklinghausen
http://www.relab.de

Professor Michael Giesing and staff
Guenther Brinks, Deputy Director of the Institute for Molecular Nanotechnology

Relab was visited as it is the 'home' for the Institute for Molecular Nanotechnology, (INMT) and the team was keen to learn how nanotechnology was being applied in the medical field. However, the main thrust of Relab's work is in cancer detection and new drug therapies. It may be that in the future, once the scientific basis for the novel cancer detection and treatment has been established, the INMT's work on standardising and simplifying analytical techniques will come to the fore

Relab is an umbrella organisation for several related medical and environmental companies, with 220 employees in total. The mission of Relab is to create and develop 'novel biological and analytical platform technologies for molecular medicine and pharma'. In the area of cancer treatment, it sees itself as the leading company for the early isolation and detection of tumours at subimaging levels.

Specifically discussed during the visit was Relab's novel techniques for isolating and characterising minimal residual cancer cells (MRCC's), which closes the analytical gap between the primary and metastatic disease. MRCC's are indicators of new and independent tumour entities; and the technologies developed by Relab allow the clinical validation of anti-cancer drugs *prior* to currently used clinical endpoints.

With regard to understanding Relab technology, it is important to understand the difference between macrotumours and microtumours. Macrotumours are tumour masses that can be detected clinically, and are the current basis of decision making, before or after surgery. Therapies cannot be monitored unless macrotumour formation occurs (or recurs). Microtumour oncology relates to small tumour masses that are below clinical detection levels. They appear in the blood stream, bone marrow and elsewhere, before the macrotumours. Better therapy decisions and monitoring can be accomplished at the microtumour level.

Relab offer a range of techniques related to pre-tumour cancer detection, discovery and validation of novel therapies, and therapy monitoring. They are also in the process of identifying the genetic foundation of cancers, using survival data. From this, genes can be identified that drive tumours; or also protect against them.
This relates to Relab's ability to analyse the genomic alteration of cancer cells, giving an indication of which patients with tumours are more likely to experience relapse-free survival.

From their work on early tumour detection, Relab came to look at the enabling technologies – and formed the Institute for Molecular Nanotechnology, INMT. INMT is cooperating with TECAN of Switzerland in their development of a novel nano-pipetting solution for the development of high-quality biochip arrays for diagnostic applications.

According to a recent paper, progress in genome analysis has created a demand for low cost high throughput technologies. DNA microarrays have been predicted to be a key technology for over a decade. Although their proportion in the research market has increased significantly, they still play a minor role in medical diagnostics. The main drawbacks are insufficient reproducibility, lack of standardisation, and expense. The paper describes the novel approaches to quality controlled production processes and reproducibility by Relab, and also the pipette robot by TECAN which can dispense volumes as small as 0.5 nl for use in these arrays.

Nano and Relab: Relab's involvement in nanotechnology relates to the use of a Swiss instrument capable of dispensing nanolitre samples, which can be incorporated into Relab's analytical technologies. There is a lesson here in the use of nanosvcale tools by companies not directly using nanotechnology.

Henkel KgaA and SusTech GmbH
http://www.denotes.henkel.de

Dr Peter Christophliemk, CEO of SusTech, and other members of Henkel / SusTech staff.
W. Gawrisch, VP Research and Technology, Henkel, and Head of New Business.

The Henkel Group was visited as an example of a more traditional company with a large portfolio of consumer products. The aim was to determine the company view of nanotechnology, their strategy for adoption, and where it was envisaged early application would be found.

Henkel is an international company manufacturing a diverse range of chemical product including adhesives, household cleaners, body care products, products for surface treatment and industrial cleaning. The Henkel Group is managed by Henkel KGaA in Düsseldorf, Germany. It employs more than 57,000 people worldwide, 42,000 of whom work for the company outside Germany, and has a turnover of DM 23 bn (1999).

Henkel see nanotechnology as a new business area, but have difficulty in deciding where to invest. Their solution is to make new alliances in order to have access to a spectrum of innovation possibilities. This has been achieved in a novel way, via a 'public – private partnership' with the Technical University of Darmstadt. Henkel have created a new company, SusTech, in which they have a 60% stake. The remaining 40% is shared between the Technical University of Darmstadt (10%) and the Professors themselves. The Departments involved are mainly chemistry and materials. This alliance has fostered a sense of entrepreneurial spirit in the University, and Henkel in return has gained access to a spectrum of competences. Henkel provides guarantees for 5 years, know-how and management/ business services. BMBF (German Research Ministry), are providing DM 5million /yr over 5 years for a project on nanoparticles. The philosophy behind the BMBF's involvement is if the alliance is successful, it will produce new products and new technologies for the marketplace, and in that location there will be new jobs created, in new start-ups and spin-out companies.

SusTech is focused on technologies with high market potential including surfaces, controlled release, processing of nanoparticles, biocomposites for teeth and bones (nanoapatites etc). Nanotechnology is seen to offer product benefits in terms of new surface properties, visual effects, stability against sedimentation (manufacturing benefit), improved mobility / penetration, and improved efficacy. The aim of SusTech is to accelerate the innovation process, speed up the commercialisation of R&D, and reduce the time to market of products and processes emerging from the academic research base. The IPR is vested in SusTech, but Henkel has first refusal to use in its business. Henkel benefits from improved access to research competence and new technologies, some of which it may want, others in which it may be financially beneficial to retain a commercial interest. However, SusTech can work with third parties, it needn't be only on Henkel projects. The longer term goal is to spin off companies in key areas.

In essence, through SusTech, Henkel has found a route to be actively coupled into the innovation process for developing products in the future, and has filed 70 nanotechnology-related patents in the last 3 years.

Dr Ray Oliver from the Mission Team gave a short presentation on ICI's view of nanotechnology with regard to future 'product landscapes' and discussed the idea that nanotechnology will be responsible for paradigm shifts in technology, leading to new materials and products with unique structures and extraordinary properties.

The Henkel / SusTech team also gave presentations on their work, including ferrofluids (with applications as diverse as cosmetics, waste water treatment, lubricants and abrasives), flexible packaging including impervious films; foils and adhesives, to name but a few. 80% of the market is currently in sunblock products. Henkel uses liquid phase routes to manufacture nanoparticles, c.f. Degussa that uses vapour phase.

Nano and Henkel. Until about three years ago, the INM (Institute of New Materials) led the way as a user of nanotechnology as the basis of new product development. In 1998 there was an explosion of interest, catalysed by a Government strategy document, and funding for infrastructure. Henkel itself tried to introduce nanotechnology as a key technology as early as 4 years ago through in-house R&D, now other large companies are following suit. Of the many Government initiatives supporting development in nanotechnology, the Centres of Competence (networks) were considered to be valuable catalysts Through meetings organised by these Centres, potential partners can be identified, and information on who is doing what is helpful.

Merck
http://www.merck.de

Dr Ralf Anselmann

A presentation was made to the group by Dr Ralf Anselmann, Head of Research of the specialty chemical division of Merck. This division in particular has embraced nanotechnology as the basis of new product development.

The Merck Group conducts its internationally oriented business under three business division headings - Pharmaceuticals, Laboratory, and Specialty Chemicals. There are 209 Merck companies operating in 52 countries employing around 33,520 individuals. There are 60 production facilities in 26 countries.

The Specialty Chemicals business is where nanotechnology is finding many real applications. The division comprises Cosmetics, Health and Nutrition; Electronic Chemicals; Liquid Crystals and Pigments/Technical Industries.

- Cosmetics, Health and Nutrition (CHN). The properties of pigments are seen as vital to imparting a wide variety of special effects to cosmetic products. Besides their optical properties, Merck's cosmetic formulas aim at achieving good ‘adhesion’ while giving the skin a feeling of softness. Merck also supplies products to other pharmaceutical industries, including high-purity chemicals, preservatives, and intermediates for synthesis. Merck also sells nutritional supplements such as vitamins, minerals and trace elements to the food industry and others.
- Electronic Chemicals. This division offers products and services for the semiconductor industry. It supplies chip manufacturers with ultrapure process chemicals as well as supporting them with Total Material Management, which also includes the recycling of used chemicals.
- Liquid Crystals. Merck develops customer-specific liquid crystal mixtures for display manufacturers. There has been a significantly increased demand for TFT displays, which have become the standard during the past years by virtue of their good readability. Extensive investments in facilities and human resources are planned in this area.
- Pigments/Technical Industries. Merck is the leading supplier of pearl- and colour-lustre pigments for the printing, plastics, paints and automotive industries. New fields of application include laser marking of plastic packaging. Major products in the Technical Industries segment are chemicals for the photographic industry and for manufacturers of optic fibres used in communication technology. Future-oriented businesses comprise materials for the manufacture of high-efficiency lithium batteries and for automotive storage heaters.

There are two research laboratories for the specialty chemicals divisions, one in Darmstadt and one in Southampton (and sponsor chair at the University). Here the focus is on nanomaterials – electronic, optic and magnetic. Nanotechnology is essential to the production of many of the ‘raw’ compounds of the sector, including photonic crystals, opals, quantum dots, nanocarbons and so on.

Dr Anselmann took the Mission Team on a whistle stop slide show of a jaw dropping selection of coated and uncoated nanoparticles, produced by Merck, demonstrating that size, dimensions, structure and surface features of nanoparticles can all be controlled.

Nano and Merck. According to Dr Anselmann*, the current growth rate in demand for nanomaterials is 60% per annum, and sales at Merck are expected to increase from 330 million DM to 700 million DM over the next three years. He sees a huge potential market for nanoparticles – they can be designed for special functions and applications (economic, catalytic etc). High value applications are possible; and the capability of making new products – for example, a razor blade coated with nanoparticles will give a smooth shave. The trend towards nanotechnology is definitely here. A major problem yet to be solved is the stabilization of single particles, and the prevention of agglomeration, involving work on the chemistry, size effects, physics and thermodynamics.*

VDI
http://www.vdi.de

Dr Gerd Bachmann

Dr Bachmann is considered as the main promoter of nanotechnology in Germany from the early days. He has been responsible for the important publication in 1998 of ‘Opportunities in the Nanoworld’, which examined in depth the potential for nanotechnology across the industrial spectrum, and laid the foundation for future initiatives.

VDI is the Association of German Engineers (shortly dropping the ‘D’ in order to become an international association) is a financially independent and politically unaffiliated, non-profit making organization comprising a membership of over 130,000 engineers and physical scientists. More than 11,000 of these members work for the VDI in an honorary capacity. Established in 1856, the VDI is today the largest engineering association in Western Europe. In Germany, it is recognized as the representative of engineers both within the profession and in the public arena.

As the leading institution for training and technology transfer, it is also a partner at the preliminary stages of the decision-making process in matters of technological policy and for all questions that engineers face in their professional or public lives. The VDI act as a vehicle for the BMBF (see below) in relation to some of their research funding initiatives.

Dr Bachmann, who works in the Future Technologies Division of VDI, described the historical development of nanotechnology research in Germany, from the first exploratory discussions and projects in 1989 to a key strategy document 'Opportunities in the Nanoworld' in 1998. The German Research Ministry (BMBF) allocated funding into the areas highlighted in the document. One of the first actions was to competitively fund the setting up of 6 Competence Centres which bring together participants from research (about 160 groups) and industry, in order to share knowledge and expertise and catalyse partnerships. They do not undertake research, but help build an R&D strategy platform. Centre topics are: Ultrathin Layers; Lateral Nanostructures, Ultraprecise Finished Optics, Nanomaterials and Molecular Architectures, Nanoanalysis, and Nano-optoelectronics.

New fields of research include extreme ultraviolet lithography and nanobiotechnology
The total funding of nanotechnology projects in Germany is around 70M DM at present

Nano and the VDI: The VDI is an industry based organisation that through its Future Technologies Division has been instrumental in identifying strategic areas for research funding in Germany that will lead to important technological competences in the future. Their document 'Opportunities in the Nanoworld' has laid the foundation of high-level strategy and funding for nanotechnology R&D in Germany, which seems well structured and moving along a well-defined, but not proscriptive, path.

Mildendo
http://www.milendo-fluidics.co.uk

Dr Holger Becker

Dr Becker was invited to give a presentation to the Mission in his role as the director of a new spin out company from Jenoptik, based in former East Germany. The objective was to learn how Mildendo became established, the support given by the German Government, the relevance of the Competence Centres to development of the business and where Dr Becker envisages nanotechnology will find application

Mildendo is a new high-tech company that develops and produces polymer microfluidic systems for life science applications. It was founded in September 2000 as a spin-off from JENOPTIK to focus entirely on developing technologies and products for rapidly expanding markets.

The objective of Mildendo is to efficiently and cost-effectively convert customers' product ideas into high-volume-production serialised microfluidic systems, helping them reduce the time to market. Central to this is the first flexible and fully automated production line for polymer microfluidic systems. Mildendo offers their customers: design, tooling, prototyping replication and back end processing facilities. Their core expertise in with PMMA, polycarbonate and polyolefins.

The need for consistent replication is vital to the production of microcomponents, and Mildendo utilises state-of-the-art hot embossing and microinjection moulding technologies. It also cooperates with leading research centres and industrial partners in its quest to offer customers optimum and flexible solutions.

Mildendo now also operates a branch in Hayward, California, within immediate reach of Greater San Francisco and the entire Silicon Valley. The US facility functions as a customer service and support centre for the American market. It also houses a technology demonstration and application laboratory where prototypes and small series of microfluidic components are produced.

Mildendo belongs to the Europractice network of microsystems and microengineering companies, whose aim is to standardise design rules for microfabrication, and ensure individual companies do not develop products that don't fit with any other. The network is driven by entrepreneurs. Most member companies are small, 10-20 people, and are 'forced' to cooperate with other companies due to complexity of the technologies and a need to exchange know-how.

Nano and Mildendo. Microsystems reduce the time to market of medical products, and the adoption of nanotechnology may reduce this time even more (see the INMT above). Moving from micro to nano will require an input from other organisations which have extensive expertise and equipment, but may have the benefit of adding in additional functionality. Dr Becker remarked that Germany was strong in non-silicon technologies. Many applications do not need silicon, but there is a real need for expertise in heterogeneous technologies. The diversity of the German approach will permit wider applications. Dr. Bachmann referred to Technology for Industry's MST 'Development-Time Map' and believes that nanotechnology will follow the same route.

BMBF
German Federal Ministry of Education and Research
Dr W Schött and staff

The objective of the meeting was to learn about the BMBF funding structure and its aims in relation to nanotechnology, some of which are achieved through the VDI who act on their behalf, meet the individuals involved, and reinforce the need to create opportunities for new partnerships.

BMBF mentioned the issues associated with supporting a technology that cut across traditional hierarchical structures, and its project team approach to coordinate the many ministries within BMBF that need to be involved in order to execute a national strategy.

The Mission team heard about the German Nanobiotechnology funding programme. Its goals are to transfer biological principles to nanotechnology, and to make use of biological nano-objects in technical systems, and to exploit nanotechnology to support biotechnology and biomedicine. Topics include nanoparticles, therapeutic and diagnostic use of nanostructured biological surfaces for technical systems (e.g. data storage), and new nanotechnologies for detection / imaging of biomolecules, in-vivo biosensors, and biochips.

Funding for nanobiotechnology is a joint initiative between the physical science and biological science research departments, complementing the funding for nanotechnology, proteomics, biochips and biosensors. Initially, funding level is 20 million euros over 6 years. 21 interdisciplinary projects were funded in 2000, and there will be calls for proposals annually thereafter.

Other topical areas mentioned that have been earmarked for new money include extreme UV lithography, photonic crystals and nanochemistry.

Nano and the funding infrastructure in Germany. The meeting with the BMBF and VDI highlighted the approach to nanotechnology from initial public discussions in 1989 to a well-researched strategy paper in 1998, backed by some serious money. This paper examined the application areas where nanotechnology might have a major effect, and where German strengths and weaknesses lay. It accepted that it was likely nanotechnology would have a dramatic and disruptive effect. It was agreed to meet the challenge that projects would need to be multidisciplinary (although this is still not always easy to achieve in practice), and that all technological options that would lead to high tech capability in the future needed to be investigated.

Caesar - Centre of Advanced European Studies and Research

Caesar is a scientific research centre funded as part of a compensation package for the move of the Federal Government from Bonn to Berlin. The operational structure, described below, is an interesting and novel one, with research firmly targeted at short term commercial applications. The reason for visiting Caesar is that nanotechnology has been identified as a major research focus.

Dr Jürgen Reifarth (Structure, mission and transfer policy of CAESAR)
PD Dr Michael Moske (Thin adaptive films)
Dr Alfred Ludwig (Smart materials)
Dr Daniel Hoffmann (Protein folding)

Background
The city of Bonn served as the German Federal capital for more than 40 years. The loss of the parliament and of government functions required tremendous structural changes in the city and region to compensate for the loss of jobs and political importance. On April 26, 1994, the German Federal Government committed itself to taking a number of compensatory measures. Four fields of action were identified, the first being the development of Bonn into a centre of science.

A compensation agreement of June 29, 1994, meant that the Federal Government committed itself to paying a total amount of 1.4 billion euro to the Bonn region, particularly to support science, research, technology and education. The most important single measure related to the Caesar foundation, which received a total capital endowment of DM 750 million from the Federal Government and the state of North Rhine-Westphalia, which generates an annual income of DM 30-35 m pa.

Caesar was inaugurated in 1995 as a new type of research centre with the aim of catalysing scientific and economic activities and creating jobs. It is a private, non-profit making research institute which carries out research at the interface of IT, physics, chemistry, biology and medicine. The goal of each research project is to create marketable innovations which lead to the establishment of start-up-companies.

This goal is reached through
- pursuing multidisciplinary time-limited research projects
- assembling temporary teams of researchers not only employed by Caesar, but also by other research organisations and industry
- developing new mechanisms for commercialisation including the substantial support of start-up-companies.
- becoming a nucleus for cooperative activities and a focal point for local knowledge networks.

Caesar currently occupies a city centre location above a shopping mall. It expects to move to new purpose built premises in 2002. The operational structure is project-oriented, with small groups of about 5 scientists undertaking fixed period tasks (say 5 years, at the end of which they leave to find work elsewhere.

The model is a limited contract for scientists, flexible salaries, and a flat organisational structure. All inventions and patents belong to Caesar; however, scientists may get licences later if they want to create a new business. The organisation has many cooperations in place with local Institutes and Universities

The research is focused on three broad topics:
- Material science/nanotechnologies
- Biological and electronic systems
- Ergonomics in communications and surgery

It is still at an early stage, however.

The Mission were given presentations on a selection of relevant projects including
a) thin adaptive films group: the testing and characterisation of: magneto resistive films, shape memory films, coatings, - including applications of magneto resistive films in advanced automotive sensors

b) protein folding group: on the characterisation of nanomachines
c) SAW – Surface acoustic wave sensor group: on sensitive mass sensors for characterising immobilised DNA molecules

Since its inception, Caesar has achieved 4 start up companies in the pipeline, and 20 industrial collaborations aimed at new product development

Nano and Caesar: Caesar is committed to technology with commercial potential, nanotechnology is a research focus, and already automotive applications have been identified for thin film sensors.

INM (Institute for New Materials), Saarbrücken
http://www.inm-gmbh.de

Dr Martin Mennig, in the absence of Professor Schmidt

The INM is a model for a research and development Institute which in a relatively short time has achieved a world class reputation for innovation in new materials. Many of these innovations involve nanoscale technologies. The Mission was keen to learn about the origin, funding and structure of the Institute as a possible mode, and why nanotechnology was seen as an important component in new materials development as long ago as 1990.

The INM, unique in the world of German materials research, was founded with the long-term R&D objective of introducing new high-tech materials on a commercial scale. The research centre, which is located in Saarbrücken, is a non-profit making, limited liability company (GmbH), led by Prof. Dr. Helmut Schmidt since 1990, who is also a Professor at the University of the Saarland in Saarbrücken.

At the INM, highly innovative high-risk long-term basic research has been funded with the aim of reducing the 10 to 15 years timescale required for the development of new material technologies from idea to the marketplace. Products and processes nearing commercial application are developed in cooperation with industrial partners, who also provide the necessary financing. This successful approach has enabled the INM to expand very quickly, into a research institute with 250 employees housed in a new a 10,000 m^2 facility, and a turnover greater than 30 MDM.

To achieve the greatest possible variety of high-tech materials, the INM adopted the strategy of integrating inorganic synthesis chemistry with chemical nanotechnology. This combination has been the key to a whole new world of materials. INM was one of the first research institutions to consistently use chemical synthesis processes, including the sol-gel process, as the basis for manufacturing materials with the assistance of nanotechnology.

In addition to the three classic material groups: metals, non-metallic inorganic materials (e.g. glass, ceramics, etc.) and organic polymers, as well as the composite materials manufactured via physical processes, Using the above technique chemical composite materials on the molecular and nano-scale level are now possible, as well as entirely new and exciting prospects for traditional materials.

The INM services include:

Consulting: The INM advises industrial companies on how to improve their products or production technologies on the basis of new materials.
Material designers and suppliers: Private technology transfer companies cooperate with the INM in adapting existing technologies to new requirements, planning production facilities, and producing materials in amounts required by users.
Application Centre for coating technologies: The Application Centre for New Materials for Coating Technology, NMO was set up as an INM project supported by the Federal Ministry of Research and the Government of the State of Saarland to fast track coating technology development. The centre, which has an interdisciplinary staff and sophisticated pilot scale equipment, acts as a technology transfer medium for the INM's diversified coating material developments.

Joint ventures: In many cases, establishing a joint venture company between the materials user and one of the materials-producing or technology-providing companies is the appropriate approach. The INM assists companies in entering into joint ventures with suitable partners.

The INM has many national and international commercial collaborations, is a key player in several networks. It is a Centre of Excellence in Nanotechnology, a network involving 65 industries and 42 Institutes. The INM also runs conferences and workshops on a variety of materials – related topics. It is one of the Centres of Competence created by the Government; has a spin-off company called Nanogate; and runs a joint venture with TNO, the Dutch Technology Organisation.

Regarding nanotechnology, INM are working in developing sol-gel technology into 'ormocils' and 'ormocers' – using interpenetrating networks of inorganic – organic molecular structures to provide functional coatings. Chemical nanotechnology (a combination of organic and inorganic colloidal chemistry) is used to combine a sol-gel or polymer matrix with 'nanomers' external ceramic, metallic or semiconductor particles to give a range of properties. These nanomers can be single component or multi component (alloy, core-shell structures). The particles can be close packaged in the substrates, widely dispersed or as nanopowders. Resultant materials can be transparent composites with advanced properties (hardness, scratch resistance, durability to name but a few). Viscosity can be controlled and this technique is leading to the development of new binding agents, transparent fillers with specific shrinkage, thermal expansion and thermal conductivity features.

Nano and INM: As mentioned above, INM is very much committed to nanotechnology, already benefiting from their strategy of integrating inorganic synthesis chemistry with chemical nanotechnology to produce 'a whole new world of materials'. INM's 'tree' of technologies perfectly illustrates this, showing how this strategy has resulted in commercial applications already, and those that are ' in the pipeline'.

Across Barriers GmbH

(Across Barriers was visited only by Nicki Smoker due to time constraints)

Across Barriers GmbH was established in order to provide new technologies and services to those working in pharmaceutical, cosmetic and chemical research and development. At the core of Across Barriers' activities are in vitro models of cell and tissue systems which are used to simulate the transport of chemicals and drugs across biological barriers.
Using these models, Across Barriers can rapidly provide drug permeability information, giving its customers the following unique competitive advantages:

- Rapid large-scale screening of drug candidates allows promising substances to be identified at an early stage of the drug development process.
- The time and costs involved in developing active agents are significantly reduced.
- Cost-intensive and ethically controversial animal experiments can be reduced to a minimum.
- The in vitro models enable the classification of drug substances that are administered by novel dosage forms, such as inhalation aerosols or transdermal methods. They also provide mechanistic information on the behaviour of substances in vivo.
- In collaboration with their analytical and physicochemical characterization division, they provide the full range of drug profiling methods required by the FDA's BCS guidelines, and thus offer their customers the possibility of being granted exemption from in vivo bioequivalence and bioavailability studies.

The use of tissue and cell cultures in preclinical research represents an intelligent and innovative step in making the development of modern drugs and drug products faster, safer and more cost-effective. Across Barriers develops and markets validated cell and tissue models that ensure its customers have the competitive edge in one of today's leading technologies.

The Fraunhofer Institute for Biomedical Engineering IBMT, St. Ingbert (near Saarbrücken)
http://ibmt.fhg.de

Prof. Dr. Klaus Gersonde and staff

The FhG IBMT is the European Centre of Competence for Biomedical Microdevices (MEDICS) within Europractice. It was selected as an important Fraunhofer Institute to visit because of its expertise across a spectrum of biomedical applications, industrial links, and a keen interest in the miniaturisation of analytical and sensor systems. The Mission team wished to establish how nanotechnology was being incorporated into the strategy of the IBMT, and its industrial clients.

There are 47 independent institutes belonging to the Fraunhofer Society, with approximately 7000 employees in total, and a budget of 715 million euros. Unlike the Max Planck Society, whose remit is to mainly undertake pure research, and its members are consequently expected to generate only a small proportion of their income form industrial collaborations; Fraunhofer Institutes are expected to generate a large proportion of their funding through industrially relevant research. On average, industry funding accounts for a third of an institute's budget, but in individual Fraunhofer Institutes, industrial funding may be as high as 45%.
[See also the British Embassy's Factsheet on the Fraunhofer Society for background. http://www.britishembassy.de – under "Research & Technology"]

This particular Fraunhofer, the Institute for Biomedical Engineering (FhG IBMT) was established in 1987. As is the way in Germany, where Institutes are built around individuals, the Government approached Dr Klaus Gersonde and asked him to head an Institute which would have a key role in the regeneration of the Saar. Staff numbers are now of the order of about 160 scientists, engineers and technicians as well as research students

IBMT places great importance on:
1. Maintaining close contact with the University – many of the Research Group leaders also hold senior positions in the University. This is also important for maintaining contacts with the students who will move into the Institute on their way to industrial positions
2. Looking outwards. It has established branches in America, China and, closer to home, in Potsdam, where the Molecular Bioanalytics group is situated.

Key research areas span medical engineering, sensors, health telematics, biotechnology, environmental control systems, materials testing, security systems, industrial process automation and in-line / on-line process control for the food, chemical and pharmaceutical industries.

Particular IBMT expertise is in: non- or minimal-invasivity, microsystems engineering, implant technology (interfaces between technical and biological microsystems), biocompatibility, robot-supported surgery, ultrasound technology, sensor manufacturing technology, magnetic resonance, computer aided simulations, monitoring systems and health telematics.

IBMT works actively on technology transfer across the whole innovation chain, and ranging from consulting, feasibility studies, prototype development, field tests, engineering and support to low- and medium-volume manufacturing. The integration of medical/biomedical, microsystems engineering and biotechnology at IBMT has given it a leading position in Europe.

This huge raft of activities is achieved through matrix management – allowing the IBMT to undertake many activities with the least number of staff. A key aspect is combining the necessary infrastructure with the expertise in the University.

Nano and the IBMT: IBMT hold the view that nanotechnology is 'waiting in the wings' both in industry and in academia in Germany; according to the Economics Minister 'although only 1.2 million people in the Saar, we are committed enough to put a substantial investment into nanotechnology'

NANOTECHNOLOGY MISSION TO THE UNITED STATES
19 –23 March 2001

TUFTS UNIVERSITY, Medford, MA
http://ase.tufts.edu/chemistry/walt/

Professor David Walt
Email: dwalt@emerald.tufts.edu

David Walt has a world-class reputation for his work in advancing the field of nanosensor arrays, using some very novel techniques. His experience in innovation in nanotechnology and investigations into the potential myriad of applications of these new techniques was of great interest to the Mission team. Similarly his views on the closeness of nanotechnology to the market place and insight into the funding and support structure in the US vis-à-vis nanoscale research is invaluable

Tufts is a relatively small but well endowed University, with about 4,500 students. In the Pearson laboratory, research is centred at the chemistry-biology interface. There is a general Interest in solving problems in biomedicine, biochemistry and analytical chemistry using organic chemistry techniques. Examples of sensors developed in the laboratory include organic vapour sensors for groundwater monitoring, O_2, CO_2, and pH sensors for blood monitoring, CO_2 sensors for seawater monitoring and penicillin sensors for bioprocess control.

David Walt's own research interests encompass: bioorganic and materials chemistry particularly the application of enzymes and cells to organic synthesis; enzyme mechanistic studies; preparation of fibre optic chemical sensors; immunochemistry, polymeric microstructures, artificial sensing systems, and combinatorial chemistry.

Professor Walt commented that 15 years ago the scale range was typically around 2mm scale; now 20nm is the norm. But, it is important not to forget there are plenty of things to do yet in the microworld! He went on to describe the research focus of his group in the nanoscale. A major theme is the extensive use of polymers and immobilization techniques. One area of investigation involves the preparation of fibre optic chemical sensors. Sensors have been developed based on fibre optic technology that can continuously measure concentration changes of various components in biological and environmental samples.
Other work involves creating arrays of near field scanning tips for microscopes.

The fibre optic sensor work began by optic image building mimicking the compound eyes of insects. It was found that cores of polymer fibres could be tapered then etched to form nanowells. Etching gives control of well depths, relating to time and depth. 'Beads' of the right dimensions will spontaneously enter these wells, due to capillary forces. High-density optical storage mirror arrays are used to address the fibres. (One of the beauties of this technique is that even working at small volumes, detection is possible using white light, however rapid evaporation means that special transfer mechanisms are needed to bring the sample to the sensor). Numerous possibilities exist using this technique from creating DNA chips capable of identifying gene mutations, to enabling DNA sequences to be worked out. Future applications include 'smarter sensors'. The aim is to create a non-specific sensor that can be trained. What they are looking at is sensor design of the 'lock and key' type.

Nano and David Walt. Professor Walt commented that microsystem science is the basis for early application of nanotechnology, from the move towards using ever-decreasing volumes, and the need to pack more elements into the same area.

Professor Edward Goldberg
Email: egoldber@opal.tufts.edu

The team were keen to meet with Ed Goldberg as his research is highly innovative, investigating biological paradigms as a long term route to massively parallel manufacturing. His work is being funded by the NSF

Professor Goldberg works in the Medical Faculty at Tufts. His lab has moved into an area of research which has just recently received NSF funding, but which he has been interested in pursuing for some time - the use of a biological paradigm to develop a technology for the massively parallel manufacture of new materials. The basis of the proposed technique is to use biomolecular 'carpentry kits' for biomimetic self-assembly of functional protein nanostructures, based on phages.

It has been observed that the head, tail and tail fibres of phages are self-assembling.
The tail contains angle protein, a binding domain and chemosensors. The various parts of the tail can be dissected, and the useful bits isolated. Connectors can be identified and mixed together so that they self assemble. The project is therefore working on converting tail fibres of phages into self-assembling nanostructures that are stiff and stable. The end game is to create light open nano arrays in 3-D that allow 'flow-through'. Professor Goldberg commented that 3-D structures are least well developed in nanoarchitecture, and this may provide one solution to their creation. Possible applications range from light structural supports to composite materials to 3D quantum well arrays.

The work of Professor Goldberg is leading to a totally novel and intriguing new approach to massively parallel manufacturing. Although applications may be some way in the future, already a company has been created to commercialise the technique, which already has investors.

UNIVERSITY OF MASSACHUSETTS, Amherst, MA

Professor Mark Tuominen
Email: tuominen@physics.umass.edu

Professor Mark Tuominen's work is also funded by NSF, who provide support to speculative research with a long end game. His specific research interests are in nanoscale / quantum electronics and self-assembly diblock co-polymers for making functional nanostructures (of particular interest to the NSF). Professor Tuominem kindly came across to Tufts to meet the Mission.

Mark Tuominen achieved some celebrity status for the creation of a University of Massachusetts logo, roughly the size of a red blood cell, but the techniques used are the result of very serious research with considerable ramifications for storage devices.

Many future applications of nanotechnology require a simple, robust, and convenient method for producing well-defined arrays of functional nanostructures. At the 10 nanometer size scale, the self-assembling morphology of a diblock copolymer film provides a practical solution to this challenge. The development of this technique, part-funded by the National Science Foundation, has the potential for creating precisely placed nanowires and still-smaller integrated circuits, needed for increasing storage capacity in computers, theoretical storage capacities of 1000Gbit/in^2 compared to current 15 Gbit/in^2 was mentioned.

By looking at nature's way of self-assembling molecules, Professor Tuominen and his team began with chain polymers. Two distinct polymers linked together (called "diblock copolymers") behave like oil and water, repelling each other while remaining inherently connected. The molecules "self-assemble" into a honeycomb-like grid of polystyrene with long, hexagonal channels, about ten thousand times thinner than a human hair. These channels can be filled and an electric field used to orient the honeycomb grid in the film for the logo to be created. Holes can be created using an electron beam to break down the chemical bonds in the filled channels. The empty channels can be filled with metal, a major step toward creating usable electronic devices.

The technique discovered by Professor Tuominen holds out great potential for extending the density of storage media, as well as linking nanostructures. Perhaps the greatest challenge, and that of nanotechnology in general in relation to devices, is interfacing with the external world. He did comment that currently this work is science driven rather than commercially driven.

THE MEDIA LABORATORY, MIT, Cambridge, MA
http://www.media.mit.edu

The Media Lab at MIT has captured the public imagination as it is perceived as a model for providing an 'off-the-wall' environment for lateral thinkers. The aim is to generate totally novel approaches and solutions to a range of scientific and social questions, by bringing together many disciplines, in a unique and creative environment free from worries about funding.
Companies (including from the UK, Marks and Spencer, BT, Post Office UK and Unilever) pay an entrance fee of anything up $250,000 to join a "club", and be associated with MIT. They take the view that the membership fee is a small price to pay for access to a raft of Intellectual Property. Subscribing companies can have royalty free licensing of any patent. Other outcomes for industrial partners include interaction with the research community, and a chance to influence students by discussing their projects. There are 35 faculties at MIT and four groups are linked to the Media Lab in the field of nanotechnology, each group is limited to 6 students.

Professor Scott Manalis
Email: scottm@media.mit.edu

In a short time, Professor Scott Manalis has gained a reputation for innovative work in several fields of research at the nanoscale. Both learning about his work, and how the environment of the Media Labs contributed to the kinds of research he is embarking on was of great interest to the members of the Mission.

Scott received a B.S. in physics from the University of California Santa Barbara in 1994, and a Ph.D. in applied physics from Stanford University in 1998, under Cal Quate, one of the inventors of the AFM. He is presently Assistant Professor of Media Arts and Sciences at MIT and a Visiting Scholar at Stanford University. His research interests are on the development of nanofabrication technologies for building molecular-scale devices, the use of MEMS for novel detection schemes, and the application of such devices to biomolecular recognition.

Scott discussed his range of interests with the team, for example, he uses FET with scanning probes to look at charges across the surface of a cell. This subtlety is achieved by growing highly uniform nanotubes directly on SPM tips and using these tips with FE sensors to look at the cell and its activity. (The control of the length and straightness of the nanotubes is critical). Scott is also involved in researching single electron transistors that can work at room temperature and underwater. Other projects he is working on in conjunction with IBM include a nanoscale cantilever for detecting damaged DNA, as well as diffraction gratings for an accelerometer that can detecting 10^{-6} fluctuations of gravity. Other research in Scott's group is on haptics, particularly the human – scanning probe microscopy interaction, with the aim of enabling people to 'feel' the attraction and repulsion forces at the atomic level while using scanning probe microscopes.

Nano and the Media Lab, in essence Professor Manalis' work is at the microscale, but examining nanofeatures, i.e. it represents the integration of nano and micro fabrication. He stated that nanomems could provide a means of enabling nanotechnology to be delivered to industry at very high yields.

Dr David LaVan, researcher in the Langer Laboratory.

Professor Langer has a world class reputation for research into a wide range of biomedical problems, and many outcomes have found commercial applications. Some projects involve micro and nanoscale techniques.

Over 60 reseachers are employed in Professor Langer's laboratory. A new recruit, Dr LaVan described some of the research projects, which may be of interest to the Mission. These include novel drug delivery techniques (estimated to be a $14 billion industry in 1997!); especially in relation to extended release, tissue targeting and non-systemic drugs. The lab also has a team working on nonviral gene therapy techniques using low density porous particles, and targeted on delivery through the lungs (NIH and DARPA funded). Other groups are looking at the combination of nano and microtechnology as a means of 'on demand' nanoparticle drug delivery using implanted microchips. A related project is the creation of a 'drug chip' for programmed delivery, activated by a tiny current. These techniques are already being tested in vivo.

Nano and the Langer Lab. Nanotechnology is seeing application in drug delivery, and perhaps in the scale of the vectors used in gene therapy; but in the main, it is still microtechnology, although there is pressure to continuous miniaturise systems.

CORNELL NANOBIOTECHNOLOGY CENTER (NBTC), Ithaca, NY
http://nbtc.cornell.edu

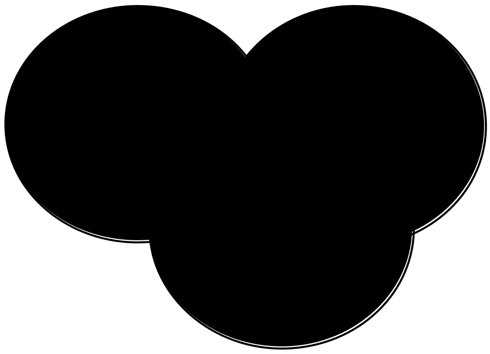
Professor Harold Craighead and staff
Email: hgc1@cornell.edu

The Nanobiotechnology Center at Cornell is seen both as the model for quality collaborative research in nanotechnology, and for its outreach programme into the wider community. The NBTC received funding from NSF and other sources in 1999, and its progress and development are of particular interest to the Mission team. Professor Craighead is another figure of global repute in the nanotechnology world. He is well known and respected in the UK, and has several ongoing collaborations with UK scientists.

The Cornell Nanobiotechnology Center (NBTC) was established in 1999 as a Science and Technology Centers funded by the NSF. Six Institutions are involved in the Center, which together combine to explore and answer biological questions through the development of nanotools to study cell and molecular biology. NSF is providing $20 million for the first five years; New York State adds $300,000 annually. There is also a grant from the W M Keck foundation to establish core facilities and support researchers. The Nanobiotechnology Center has the further benefit of close links with the Cornell Nanofabrication Facility and the Cornell Center for Materials Research, which provide a complementary and supportive infrastructure.

Apart from its innovative and diverse research programme, the Center works to create links with the private sector, and offers the opportunity for business to join in research and other partnerships. Benefits include the faster transfer of new technologies to industry, and the opportunity for researchers to work within companies. A key objective is to to train people for industry and the main 'product' of the Center is happily agreed to be students. The students leave Cornell with interdisciplinary skills, increasingly vital for industry; or move on to other research.

At the Cornell NBTC, the emphasis is on the unifying activities of the undergraduate nanobiotechnology course. Microfabrication techniques are taught to biologists, and the basics of biology to engineers and physical scientists. Research is based on three platforms, molecular, surfaces and devices:



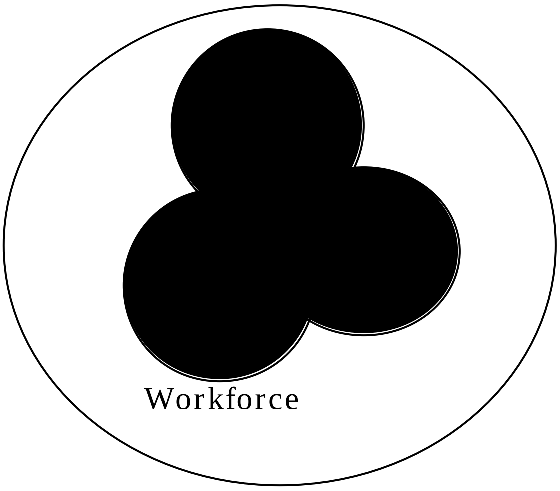
Within these key areas, there are 6 main programmes, each with several projects. The programmes comprise:
Molecular Templates – concerned with the assembly of controlled arrays of molecules;
Bioselective Surfaces – defining and exploiting the topographical and chemical characteristics of a surface that influences the behaviour of biological systems;
Molecular Filtration enabling the exploration of biological systems, leading to the characterisation of organisms at the genomic level,
Sparse Cell Isolation, the isolation of cell types that represent less than 1% of the population**;**
Microanalysis of Biomolecules – the creation of analytical tools that can interface with single cells;
Molecular Motors –development of a novel class of nanoscale devices that can deliver rotational or linear movement.

Some key projects include: rat brain cells grown on silicon chip: the potentials is living neurons connected to silicon circuitry; plant fungi sensing surface topography to initiate infection: a functional study of fungal cell growth and differentiation; powering nanomachines with molecular motors – converting chemical energy (ATP) of living organisms into useful mechanical energy.

This bringing together of different disciplines is a very complex situation for the Centre in terms of managing funding. However, the upside is that students from a broad range of backgrounds can to be exposed to nanotechnology. Presently, 30 PhD's are being funded from 25 faculties across the 6 participating Institutions. Other NSF – funded Centres like the one in Cornell are generally funded for 10 years, but need to rebid for funds after 5. Companies are keen to be associated with them, because in this era where there is a shortage of well-trained scientists, the link with Cornell is viewed as a means of obtaining new, well qualified staff.

An important part of the Cornell NBTC is the Outreach programme, and the 'Education Coordinator' has the responsibility to link NBTC with students of all ages, and inform the wider community. 10% of the NSF budget is generally channelled into this activity. Some of the activities include a travelling nanoworld exhibit, a summer Institute for teachers, an interactive website, and a science club for middle school girls. Currently, a booklet on nanobiotechnology is being produced for schoolchildren, centred round the human body.

Nano and Cornell NBTC. Nano has become very firmly placed at the centre of a research agenda here, particularly in the exploration of phenomena at the interface between the physical and the life sciences. To do this there must be real multidisciplinary teams who can understand each other's language and work constructively together. Although it is early days, there is real promise and excitement in the research projects that are underway, even though the Center sees quality students who are fit for a career in industry or academic research as its main product. To defuse misapprehension by the public at large about nanotechnology, and raise the awareness of young people (as the next generation of students), there is a large and committed effort put into outreach.



THE CORNELL NANOFABRICATION FACILITY (CNF)
http://www.nnf.cornell.edu/
http://www.nnun.org

A visit to the nanofabrication facility at Cornell was also high up the agenda of the Mission team, in order to determine the benefit or otherwise for industry and academia of having such an infrastructure to support research and development; how it operates and is funded.

Dr Sandip Tiwari
E-Mail: tiwari@cnf.cornell.edu

Dr Tiwari is Professor of Electrical and Computer Engineering and Director of Cornell Nanofabrication Facility. The facility belongs to the National Nanofabrication Users Network, of which Professor Tiwari is the Director also. The network comprises Cornell, Howard, Pennsylvania State, and Stanford Universities, and the University of California at Santa Barbara, all established in 1980. Each tends to have a slightly different emphasis. Other nanofabrication facilities also exist at Berkeley, Texas and MIT.

The CNF is an infrastructure facility created by NSF funding. It also supports small business development. The NSF provide around a third of the necessary funds, mainly in support of staff. $80 - $100 million is required annually, and is received from the federal and State government, and industry. The CNF has been established for more than 21 years, originally as a Microfabrication Center, and since its inception has provided services to over 600 research projects. The facility can be used by anyone, and at any given time there are 250 Cornell students; 30-40 staff and approximately 300 outside users. All interaction with the facility – bookings etc, is achieved via the web - http://www.nnun.org

There is a considerable emphasis on safety, with. 20% of staff time spent on safety, 20 - 30% on tool development and 50% helping users. In the future, the Facility may work with commercial tool developers. One of the main benefits of the facility is the quality of the science students it delivers from Cornell.

Topics are as diverse as astronomy and plant pathology, and there are projects in the emerging fields of integrated optics and microelectromechanical structures (MEMS) as well as the more conventional microelectronics, physics and materials research. There is a 30%

pa growth rate in users every 3-4 years. The greatest growth till recently was in the use of the facility for biological projects, but now chemistry is the most popular. According to Professor Tiwari, most of the work could in reality still be classified as being mems, rather than actual nano. There is also an emphasis on outreach in the CNF, with regular courses run for industry that can also be accessed through the internet. Across all the facilities of the National Nanofabrication Users Network, the statistics for the year 2000 are as follows: 1450 unique users; from 29 US states, 7 foreign countrie, 50 start-up companies.

The research interests of Professor Tiwari himself are varied, and include: Small devices and their circuits; ideas and technologies that allow continuing evolution of microelectronics in functional integration; interesting offshoots of small structures in other areas using silicon technology as a foundation. These subjects include: experimental and theoretical investigations of ultra-small transistor structures, use of nano-structures through device applications of single electron and reduced density of states effects, development of circuits that connect the small structures with the CMOS world, low power circuits, and three-dimensional integration for logic, memory, analog, and mixed-signal applications.

Nano and the Cornell Nanofabrication Facility. The need for such a facility is demonstrated by the growth in its use across the community, bringing together individuals from many disciplines, both academic and industrial, and from geographically widespread locations. The CNF is well organised in having good staff resources, an efficient booking system (through the internet) and even accommodation for users. The use by start-ups is growing, and the CNF is providing increasingly vital support for new high technology businesses.

CORNELL CENTER FOR MATERIALS RESEARCH

Professor Emmanuel Giannelis
Email: epg2@cornell.edu

Professor Giannelis has a world-wide reputation for his research into new materials which can be characterised at the nanoscale. His work has many applications in different fields including novel coatings and drug delivery.

Professor Giannelis' researches a wide range of material properties, but for the benefit of the mission he discussed his work with reference to hybrid nano- bio- materials. His interest lies in molecular design, synthesis, and characterisation of new materials by chemical means. A particular goal is the development of design principles and synthetic approaches that will enable the building of materials with complex spatial structures by controlling their chemistry at the molecular level.

Professor Giannelis treated the team to a tantalising whistle-stop tour of his current research in hybrid materials. He discussed how dispersion can be maintained, and what occurs with the mixing of hydrophilic and hydrophobic molecules. It is the properties *at the interface* of surfaces which dictate the properties of the material as a whole, and in this class of materials the novelty is that the material is essentially all interface with very little bulk material. Interactions between polymers and disseminated organics can be fine tuned, and their performance consequently changed, giving rise to new phenomena as a result. For example, a nylon nanocomposite with only 2% inorganics exhibits

- Increased modulus of elasticity and strength (stiffness effect)
- Increased heat distortion (temperature effect)
- Reduced inorganic content to deliver these properties (therefore not heavy)
- Increased resistance to fracture (toughness)
- Improved electrical properties

QED – a new material!!

With nanocomposites, there need be no trade off between stiffness and toughness. The challenge is dispersal. Nylon for example is very polar and simple to disperse.

Another example is polymers that can be intercalated with DNA or drugs or fluorescent substances for delivery into a living cell. The polymer can be biodegradable; the trade –off is biodegradable – not fit for the purpose; but with the new design possibilities as discussed above, there need be no trade off. Nanostructuring provides the basis for new materials as the characteristics relate only to the interface. In fact, how the included particles behave flies in the face of thermodynamics!!

In conclusion, new materials can be created by the bottom-up approach; inorganic particles can be disseminated in a polymer matrix; the resultant properties avoid traditional trade-offs; properties of the material are dictated by the interface.

Research topics in the department include:
Polymer Nanocomposites: design, synthesis, characterization and properties
Structure and Dynamics of Polymers in Confined Environment: neutron and x-ray scattering, nuclear magnetic resonance, dielectric spectroscopy, positron annihilation, ion beam analysis, computer simulations
Self-assembling Systems: semiconductor patterning and deposition via self-assembled structures Integrated
Thin-film Capacitors: materials and processing of integrated capacitors and other passives for microelectronic applications
Metal-Ceramic Composites: synthesis, processing, mechanical properties, modelling

Nano and Professor Giannelis: Professor Giannelis' work demonstrates once again that early real applications for nanotechnology are being found in Materials Science, but there is a whole world out there of new materials with amazing properties that need not be complex or difficult to produce.

YALE UNIVERSITY SCHOOL OF MEDICINE, New Haven NY
Department of Surgery

Professor Richard Satava M.D., FACS, FioN.

Until last year, Dr. Satava managed the DARPA Advanced BioMedical Technology (ABMT) Program. His specialism is diagnosis and treatment of disease (including robotic surgery) using advanced telematics and virtual reality. He is also a respected advocate of education and training for the military (and others) using virtual reality. He is a member of the Emerging Technologies, Resident Education, and Informatics Committees of the American College of Surgeons (ACS).

DARPA funds outcome-oriented projects. A flavour of this can be gained by considering the outputs from the ABMT program recently managed by Dr Satava, which can include training. (Many of the projects are undertaken in conjunction with commercial companies, and several involve nanoscale science)

ABMT Program - Diagnostics Projects Outcomes:
A medical telesensor ASIC, capable of transmitting readings including pulse, blood pressure, temperature (accurate to 0.1oF), and other signals from personnel in the field.
A personal status monitor that consists of a GPS locator, and vital signs monitor
A wearable motherboard, or intelligent garment which can detect bullet wounds, and monitor vital signs systematically and unobtrusively
The intelligent bathroom, for multiparametric health monitoring
Hand held ultrasound
3-D ultrasound imaging
Virtual endoscopy

Therapeutics Projects Outcomes:
Telesurgery and telerobotic surgical techniques
Robot 'hand' to improve the performance of minimally invasive surgical techniques
MEDFAST system of remote therapeutics
Microdexterity robotic arm for remote patient care

Microrobot for navigating the intestines
MEMS micromuscles for propelling microrobots
Artificial muscles for robots – light activated polymeric actuators
LSTAT – Life support for trauma and transport
Unified man-machine interface –robotic surgical systems for minimally invasive surgery

Education and Training Outcomes
Virtual reality based simulator of abdominal surgery
SIMCOR – for medical training of battlefield personnel
The operating environment of the future – next generation, multi platform integrated medical environment
Tissue force measurement – development of an endoscopic grasper with a haptic user interface
Haptic input device for telesurgery
3-D holographic image display in high resolution and full colour

Dr Satava discussed the role of DARPA and the US Army Material and Research Command (AMRC) in general. They are essentially funders of 'real solutions' to problems. The imperative of DARPA and AMRC is essentially to ensure technological superiority of the US worldwide, and identify the appropriate military response to all possible weapons of mass destruction. Presently there is a particular emphasis on the biological weapons, and DARPA is funding research into at miniature (nano) devices for the recognition of 'designer' agents of germ warfare and for drug delivery. They are increasingly concerned about the products of genetic engineering.
Nano is 'real' in terms of funded research, and money is being spent on creating on interdisciplinary research teams working at the conjunction of biology, information and communications technology and nanotechnology. Cell biologists work together with electronics and communications engineers on the next generation of computers, devices and materials.
Regarding space travel, nanotechnology is seen as the route to 'quicker, faster and cheaper, with less power' and projects are being funded with these applications in mind. The route to the widespread adoption of nanotechnology is still perceived as 'evolutionary', rather than 'revolutionary', through driving down the scale of MEMS.

Nano and Dr Satava. The need for progressive miniaturisation, even into the nanometre range has a special appeal for the military. The addition of increased functionality along with miniaturisation allows the production of increasingly complex systems. Working at the junction of the biosciences, ICT and nanotechnology offers the potential for totally new products and processes. But applications are still at the research rather than the development stage.

PACKARD BIOSCIENCE, Meridian, CT
http://www.packardbioscience.com/home4.htm

Dr Frank Witney and Staff

Packard Biosciences was visited as a major player in the bioanalytical field. The objective was to determine how nanotechnology might affect new products or processes within this kind of industry.

Packard BioScience is a leading developer, manufacturer and marketer of instruments and related consumables and services for use in the life sciences and nuclear industries, with 50% of their customers in the US, 35% in Europe and 15% in Asia. They are primarily focused on the rapidly growing areas of drug discovery, genomics, proteomics and biochip analysis, and are developing integrated platforms built on their own wide range of technologies and instrumentation. These platforms are designed to support the industrialization of drug discovery by bringing the benefits of miniaturization, automation and ultra-high throughput analysis to these areas. Packard see themselves as providing across-the-board integrated solutions for drug screening applications that will increase the speed, reduce the cost, improve data accuracy and enhance the productivity of their customer companies. They are therefore keen to identify bottlenecks in the process which can provide further market opportunities.

Packard, like other companies, is active in its drive toward miniaturisation, as it potentially offers huge economic benefits. Although 15% of sales revenue is spent on R&D, this is mainly on the 'D' side, and the 'R' is usually achieved by acquisition.

Packard see opportunities for nanotechnology in integrated devices, i.e. in enabling multiple actions to be performed on one device. However, at present the cost is the limiting factor, as current leading edge devices cost more to make than people are willing to pay, and offer little improvement in data quality. Furthermore, the problem of fluid handling in very small devices is still not fully resolved. Nanotechnology though represents a new way of thinking, and in order to be usable, needs to 'come out' of the clean room environment. Benefits are reductions in use of analytes. Possibly first applications would be as part of a hybrid system, probably in about 5 years. However, on reflection, nanolitre dispensing would be useful now!!

Nano and Packard: Nanotechnology is seen by the company as bringing added value and increased functionality to existing techniques, but it must be useable in a 'normal' environment, and offer cost benefits and reliability compared with existing products

ORCHID BIOSCIENCES, INC., Princeton, NJ
http://www.orchidbio.com/

Gary Schnerr and staff

Orchid was an early user of microarray technology, and has progressed into the new arena of genotyping, as a basis of drug discovery, tailored to the individuals response and needs. Over a period, Orchid have built a database of genotypes which should be a valuable asset for its future. The Mission was keen to explore where the company envisaged that nanotechnology would offer benefits to them.

Orchid began a spin out company from the Sarnoff Research Center in 1995. The company now has offices in 5 locations, with the HQ in Princeton. Orchid's basic business is in the developing and commercialising of technologies, products and services designed to measure and use information related to genetic diversity. The company focuses on the manufacture of proprietary technologies that significantly enhance the way information is generated about single nucleotide polymorphisms ('SNPs') - the most common form of genetic diversity. The company was originally involved in microfluidics and chip-centred applications, but over a period of time, through acquisition and R&D, it became involved in identity testing (paternity, bone marrow compatibility, forensics) and now sees its core business targeted drug discovery and pre-clinical development, especially in relation to genotype. Orchid currently hold over 230 patents.
It uses its own proprietary arrays, which consist of wells formed by a gasket on a special glass substrate, providing clearly distinguished colours as test results. The basic technology is relatively simple, relying on capillarity and a slight pressure to create the flow through the arrays. The reactor wells can be sealed and removed, and on-chip pumps and valves use nanolitre volume control. This SNP procedure can identify up to 100,000 genotypes a day.

Orchid's technology in relation to genotyping puts it in pole position to meet the increasing requirement to customise drugs; i.e. make drugs more targeted to the individual. Over 100,000 deaths occur each year in the States due to adverse drug reactions.

For Orchid, there are clear advantages in miniaturisation, as follows:

- Reduction in volumes of sample and reagent required
- Faster response times
- Smaller footprint of equipment
- Better environmental control
- Enhanced integration

At 250 nl per SNP, reaction rate is 2 minutes; at 100 nl, it is 5 seconds!! ‘All biological advances force instrument changes to absorb them’

Nano and Orchid: Nanotechnology may offer cost reduction in the future; but reliability is even more important than cost, as quality is at a premium. Nanotechnology may offer benefits in reducing the use of expensive reagents; and possibly to elimination of some steps in the analytical process, and provide advantages of robustness and efficiency.

THE NANOTECHNOLOGY CENTER
Ben Franklin Technology Partners of Southeastern Pennsylvania, Philadelphia, PA

http://www.sep.benfranklin.org/

Dr. Barry F. Stein, Ben Franklin Technology Partners
Professor David E. Luzzi of the University of Pennsylvania,
Professor Kambiz Pourrezaei of Drexel University

The Ben Franklin Technology Partners of Southeastern Pennsylvania (BFTP/SEP), an independent not-for-profit economic development organization, was established in 1982. It belongs to a statewide network that supports the technology sector in the region as a basis for new economic growth.

In September 2000, Ben Franklin Technology Partners were awarded $10.5 million by the Pennsylvania Technology Investment Authority (PTIA), to establish the Nanotechnology Center in Southeastern Pennsylvania. The intention is to bring together corporate and academic partners to accomplish nanotechnology research and development that will produce high commercial returns. There has been a shift from funding universities to develop technology to supporting small companies in exploiting technology. Activities of the Center include accelerating the commercialisation of new nanotechnologies through the transfer of discoveries and intellectual knowledge from universities to industrial partners.

The funding is provided directly to the Ben Franklin Technology Partners to establish administrative, fiscal and contract management services. BFTP will be responsible for commercialisation and company investment functions. The current management committee that comprises Drexel University and the University of Pennsylvania as well as BFTP will be joined by members of the private sector, but with the proviso of not involving discrete corporate entities that may generate a conflict of interest. The Center is in the process of creating a Scientific Advisory Committee, bringing together representatives of corporate industrial research and development.

The goal is to establish Pennsylvania as one of the leading locations internationally for nanotechnology, and create a regional economic development strategy to stimulate new growth and economic wealth for the area. The Nanotechnology Center (very much like the Institute of Nanotechnology) has chosen the areas of human health and biomolecular science as an initial focus, building on the strengths of the region. The goal is to establish a research programme in nanobiology that will support a collaborative, multi-institutional, interdisciplinary research programme in key enabling areas and provide a mechanism of commercialising the resultant IP. According to Barry Stein, because the Center has been conceived within an economic development context, its activities are designed to integrate participation of the commercial sector at all levels, and the proposed Board of Directors of the Center will include Government, economic development agencies, companies, lawyers and investors.

The MITRE Corporation, McLean, VA
http://www.mitre.org/research/nanotech/

James Ellenbogen, Nanosystems Group
Email: ellenbgn@:mitre.org

The MITRE Corporation is a kind of 'technology watchdog', constantly monitoring science and technology in the US, and providing feed back into US Government programmes. In the words of MITRE 'It aims to understand what is happening out there, and may be at odds with the general perspective'. However, MITRE was not commissioned to advise on global strategies but more towards specific programmes.

Dr Ellenbogen heads the Nanosystems Group within Mitre, and apart from also keeping a watching brief on technology 'movement' his specialism is the solution to what happens beyond Moore's Law. According to Dr Ellenbogen, the IT revolution has been a *miniaturisation* revolution – see Scientific American, April 2001. The ability to reinvent every 2-3 years is critical (Paul Pakan, Scientifc American).The research program of Dr Ellenbogen's Nanosystems Group consists of a broadly-based set of investigations on nanometer-scale systems. One element of the research is on potential technologies and designs for electronic nanocomputers integrated at the nanometre scale. DNA computing, quantum computing (Los Alamos) and nanomechanical computing are under investigation. The primary focus of the project, however, is on nanosystems modelling. The idea is that if a nanometre scale computer can be 'visualised' now, it may enable industry to miniaturise electronic devices even faster.

Among the other ongoing tasks is the development of a 'computationally generated immersive virtual environment' that will provide the user with a realistic, "hands-on" experience of manipulating atoms and "sculpting" nanostructures.

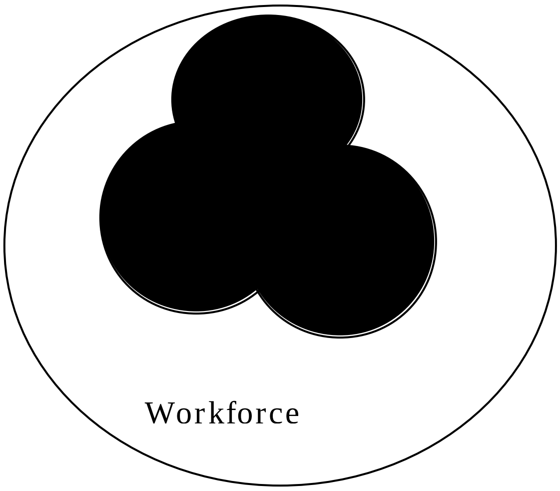
Nano, MITRE and Virginia State: Nanotechnology is now a focus for Virginia State, where there is a consensus from academia, business and government regarding its importance. A range of assistance has been made available for start-ups including business incubators. The state is already famous for its e-business companies (which emerged as a result of downsizing the MOD), and nanotechology is seen the next wave of enterprise creation. Dr Ellenbogen issued a timely warning that it was important not to oversell nanotechnology.

THE NATIONAL SCIENCE FOUNDATION, Arlington, VA
http://www.nsf.gov/

Eve Barak. Cell structure and function
Lance Howarth. Materials Research in the Directorate for Mathematics and Physical Sciences ($200 million / year. $50 million on nano)
Larry Goldberg. Engineering Division (electronics / photonics/ devices)
Mike Roco: Control of NSF nano strategy and funding.

The National Science Foundation is an independent U.S. government agency responsible for promoting science and engineering through programs that invest over $3.3 billion per year in almost 20,000 research and education projects. In 2000, the NSF announced a National Nanotechnology Initiative (NNI) for which it was seeking approximately $500 million dollars funding for interdisciplinary blue-skies research in the fiscal year 2000-2001. The final budget was around $422 million dollars, but the message that nanotechnology was deemed to be an area of critical importance was flagged up, not only in the US, but across the major industrial countries of the world. This year, the budget is expected to be $485 million dollars. The programme is now hugely oversubscribed, and is experiencing a bottleneck, success rate for submissions is typically 15-20%, but the fear is it could be as low as 5%. It is likely however that funding for nanotechnology in the US will be consistent over the next 4 years; there may even be some increase.

NSF funding is focussed on academic institutions, and on all areas of science and engineering. It spends 16% of its total funds on education (about 3-4% goes on nano).
NSF funding goes mainly towards the more speculative sky research, and in providing support for infrastructure, such as the National Nanofabrication Network.



As typified by Cornell, Centres funded by the NSF are generally funded for 10 years, but recipients need to rebid for funds after 5. NSF funding can be leveraged by local state funding. Companies are keen to be associated with the projects, as a route to obtaining the kinds of students they need. The aim of the Centres is primarily to provide people for industry.

Many nanocentres have also now been created independently in Universities with their own funds, e.g. in Princeton, NW University. Industry has also responded well, and HP has 30 or 40 postgraduates working on nano, and IBM say that it is their first priority.

Regarding the Department of Materials Research within the NSF. About $45 million dollars was spent on nanotechnology on awards to individuals, awards to research centres (29 are explicitly involved in nanotechnology), and on national user facilities, such as synchrotron radiation centres, the National High Magnetic Field laboratory.

Funding in 2001
There will be six major components of the NSF funding programme, namely:

- Biosystems at the Nanoscale
- Structures, Novel Phenomena and Quantum Control
- Device and System Architecture
- Multi-scale Modelling and Simulation
- Societal Impact

And three funding modes:

- Teams, Centres, Exploratory Research

Also awards will be made via existing programmes

The NSF has specific strategies for supporting international collaborations, but no policy to work with one country or industry. DARPA is the only agency that works directly with industry. There is currently an NSF – EC coordinated call for proposals – see the NSF Disseminated Materials Research website; and applications may be submitted on a bilateral country-by country basis. Regarding collaborations, new ones are favoured. Regarded as a win-win situation. NSF is keen to encourage student exchanges, but the problem is that US students don't like to go abroad!

In short, the goals of the NSF can be simplified as People - Ideas - Tools

Nano and NSF: In 2000 the US Government demonstrated its commitment to nanotechnology by devoting $422 million to funding nanotechnology across different disciplines, and based on a well-thought out strategy document prepared by Dr Mike Roco and his group. This has galvanised the rest of the world into action, apart from a few industrialised counties who had already laid the foundations for nanotechnology R&D (such as Japan and Germany). The further commitment by the US leaves us in no doubt that they view nanotechnology with utmost seriousness as a key area of technology that will deliver economic and social benefits.

Publications
WTEC Panel Report
Nanostructure Science and Technology
Ed R W Siegal Published by Kluwer 1999

IWGN Workshop Report
Nano Research Directions
Ed M C Roco. Published by Kluwer 2000

DEFENSE ADVANCED RESEARCH PROJECTS AGENCY (DARPA)
http://www.darpa.mil/

Dr Christie Marrian, NRL

DARPA was established in 1958. It is an organization of 240 personnel (approximately 140 of which are technical) and a directly managing a budget of $2 billion. Programme managers are generally on a three year secondment. Dr Marrian joined in 1998, and was due to finish his secondment shortly after our visit. In his previous existence he ran the nanoelectronics facility at NRL, working under Fabian Reese at Stamford on nanoimprinting, and including applications in the patterning of organic materials. He has also been involved in a molecular electronics programme, researching diodes, switches and resettable switches based on organics.

DARPA has a policy of encouraging proposals from small businesses, but in this case, nanotechnology is not really a small business activity. DARPA also provides funding for academics, Masters students etc, as feedstock for the economy. It is especially keen on outcomes-oriented research. Regarding intellectual property, the only proviso is that the Government is given royalty-free licences for its own use.

DARPA is running 5 or 6 programmes related to nanotechnology including:

- Materials – for the generation of new properties
- Quantum Information for Society and Technology
- Advanced Microelectronics
- Advanced Lithography
- Spintronics
- Bionanosesnors for pathogens.

DARPA needs to identify every possible pathogen that an enemy might produce, and be able to counteract it.

Projects under Dr Marrian's supervision include the Molecular electronics programme. With regard to the procedures for applying for funding, announcements regarding programmes are available on the DARPA website including preliminary call details, full details, deadlines for submission of proposals, then evaluation. Specific deliverables are always identified. Projects must meet the requirements of 'domination' and 'economic' – plus also nano! Compare this with the approach of the NSF who are into 'insight and knowledge'. NSF funding is also smaller in scope, with lower levels of funding. Knowledge and discovery is their prime motivation.

DARPA on the other hand addresses broad projects in selected areas; and funds work aimed at developing ways to solve a given problem

Nano and Dr Marrian. The problem with nanotechnology and nanosystems is the nano to macro transition. It is easy to design in the desired functionalities, but how can they be 'wired' together, or connected into the macro world?

Participants

Professor Jon Cooper[2]. Chair of Bioelectrics and Bioengineering. Dept Electronic Engineering, Glasgow University, jmcooper@elec.gla.ac.uk.
Research Interests include: microsystems for biomedical research and surface analysis of bioelectronic interfaces, and involves national and international collaborations with academic (for example MPI Mainz, CNRS Paris, TU Eindhoven) as well as industrial partners (for example Glaxo-Wellcome, Philips and Gene Logic) and is focussed through the Bioelectronics Research Centre (within the Department of Electronics) at Glasgow.
http://www.elec.gla.ac.uk/Personal_pages/Cooper_page.html

Professor Graham Davies[1], BT http://www.nano.org.uk/graham_davies.htm
Professor Davies is responsible for BT's £60 million strategic research programme, and managing technology acquisition worldwide. Instrumental for shaping BT's corporate research strategy. He sits on the UK's Materials Foresight Panel with special responsibility for nanotechnology; the Higher Education Funding Council's research assessment committee; and the Economic and Social Research Council's committee on research evaluation.

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Dr de Mello's research group forms part of the Zeneca / SmithKline Beecham Centre for Analytical Science within the Department of Chemistry at Imperial College. It specialises in the development of miniaturised chemical analysis systems and sensitive detection methods. Interests are centred on state of the art analytical chemistry and molecular spectroscopies, and primary research falls into the following categories: miniaturised total analysis systems (µ-tas); single-molecule detection; evanescent wave induced fluorescence spectroscopy; time-resolved fluorescence spectroscopy

Professor Donald FitzMaurice[1,2], Professor of Chemistry at Dublin, donald.fitzmaurice@ucd.ie T: 00 353 17062109. He is Director of Nanomat Ltd http://www.nanomat.com Research interests include preparation and characterisation of nanocrystallites and nanostructured materials self-assembly of organised nanostructures, smart window and display devices, nanocrystal drug delivery. He is a director of 2 start-ups under the umbrella of Nanomat, to commercialise these technologies.

Mrs Mandy Mayer[2] CBE – Director, Innovation and Business Development at the Department of Trade and Industry mandy.mayer@dti.gov.uk
Mrs Mayer is responsible for developing and delivering a range of services which help UK industry access and exploit technology and best practice. Nanotechnology has been recognised as one of the key underpinning technologies where industry needs help in recognising its potential and understanding the step change in processes and applications it will bring across a number of sectors

Dr Justin Molloy[2] University of York, Molecular Motors Group, jem1@york.ac.uk
The interests of Dr Molloy's group include: Single molecule techniques to investigate the mechanism of molecular motors. He is responsible for development of an optical tweezers force transducer with piconewton-nanometre resolution. The 'tweezers' use photon pressure, directed along gradients of light intensity, to draw small dielectric particles towards a focus of laser light, produced by a microscope objective lens. Optical forces can be calibrated and used to counter-balance those produced by the interaction of single molecules. In principle the technique can be adapted to observe the behaviour any pair of interacting molecules. http://motility.york.ac.uk:85/

Dr Ray Oliver[1], ICI ray_oliver@ici.com
Dr Oliver is the manager of the Powders & Dispersions R&D Team. He is responsible for the delivery of new products through commercially competitive manufacturing technologies, with a particular interest in the application of nanotechnology

Dr Nikin Patel[1], manager, Molecular Profiles Ltd, Nikin.Patel@nottingham.ac.uk
http://www.biomateria.com/molecular_profiles_ltd.htm
Molecular Profiles is involved in the application of surface biophysical tools for industrial problem solving and for supporting industrial research and development programmes. Expertise includes surface chemical analysis, polymer science biocompatibility, surface modification, biomedical devices, molecular immobilisation, biosensors, drug dosage forms, diagnostic systems, imaging techniques and issue engineering.

Dr Mike Pitkethly[2], Commercial Director, DERA, mjpitkethly@dera.gov.uk
Dr Pitkethly's interests extend across the materials field with particular interest in multi-functional materials. Examples of these include materials with magnetic, electric and optical capabilities. In addition materials for MEMS and other micro and nano-scale applications are of interest.

Professor John Ryan[2], University of Oxford, Department of Physics,
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Professor Ryan's research includes ultrafast and near-field optical spectroscopy of semiconductor nanostructures. Quantum wires and quantum dots are being investigated in order to understand their fundamental electronic and optical properties, and to explore their potential for optoelectronic device applications. Quantum optical processes are being studied in semiconductor devices including waveguides, lasers and LEDs. A new nano-biotechnology programme is being developed which includes synthetic and biological molecular motors, membrane protein dynamics - ion channels and receptors, and biomolecular electronics.

Ottilia Saxl[1,2], Institute of Nanotechnology o.saxl@nano.org.uk
Ms Saxl is the founder and current CEO of the Institute of Nanotechnology. The Institute grew out of the Centre for Nanotechnology, part funded from 1994-1996 by the UK Government's National Initiative on Nanotechnology, and holds a comprehensive database on nanotechnology activities across Europe. The Institute has recently inaugurated its European Board. http://www.nano.org.uk

Professor Ian Shanks[1,2], Unilever Ian.Shanks@unilever.com
Professor Shanks heads Unilever's Corporate Engineering and Science activities. These include research into the possible applications of nanotechnology (including microengineering) in Unilever's manufacturing processes.

Dr Kevin Shakesheff[1], Nottingham www.nottingham.ac.uk/pharmacy/tissue-eng
Dr Shakesheff heads the tissue engineering group, a highly multidisciplinary group developing new methods of engineering tissues using polymer scaffolds. The Group works on the regeneration of liver, nerve and other tissues using novel biomimetic materials synthesised in own labs. Activities include: polymer synthesis; surface engineering, liver regeneration, patterning and nerve regeneration, prevention of bacterial adhesion, bone regeneration.

Mrs Nicola Smoker[1], International Technology Promoter (ITP), PERA
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Nicki is the ITP responsible for Germany and focuses on environmental, process and life sciences. She works with UK industry to promote collaborations with German companies and research organisations.

Professor Anthony Walton[1], Department of Electrical Engineering, Edinburgh University anthony.walton@ee.ed.ac.uk
Professor Walton has been involved with the microelectronics industry in a number of areas which include silicon processing, microelectronic test structures, Design for Manufacturability (DFM) and Technology Computer Aided Design (TCAD). Present interests include the optimisation of semiconductor processes through the integration of the experimental design and TCAD simulation tools. Recently he has been looking at the combination of biological structures and 'smart' silicon.

1 = German Mission, 2= USA Mission

Thanks are due to **all** our hosts in Germany and the USA. The people we chose to visit are busy people, and we are grateful to them for giving us so much of their time and attention.

In Germany, particular thanks are due to Boyd McCleary, Director-General for British Trade and Investment Promotion in Germany for hosting our reception in Dusseldorf, and all those who kindly attended it. The reception was a huge success, allowing the team to meet and talk with a wide cross section of the nanocommunity in Germany in a social setting. Special thanks are due to Gerd Bachmann, Holger Becker and Ralf Anselmann who travelled to Bonn to meet with the team and talk about their work. Members of the German Research Ministry also kindly hosted a morning's discussions, which we are also most grateful for.
Very special thanks are due both to Nicki Smoker, International Technology Provider, and Ursula Roos from the British Embassy Bonn Office, Research and Technology, who worked tirelessly to provide information, organise invitations and arrange visits, and have contributed to a large extent to this final document.

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Special thanks are due to Dr Julie Moses, science and technology analyst at the Washington Embassy for advice, and arranging the Washington section of the trip.

Most of the companies and organisations we visited kindly provided us with lunch and other refreshments, for which we would also like to extend our most grateful thanks.

Finally, thanks are due to the DTI for initiating and supporting the missions, especially Andy Carter, and mention must be made of Julie Strang at the Institute of Nanotechnology for ensuring a problem–free USA Mission.

Ottilia Saxl
Institute of Nanotechnology
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