A flexible approach

Andrew Turberfield may not be a typical scientist, but the University of Oxford physicist's journey from academia to industry and then back again — with detours in biology and engineering — may resemble a common roadmap for nanotechnologists.

Turberfield, a semiconductor physicist by training, decided to spend 1998 on sabbatical at Lucent Technologies' Bell Labs in New Jersey because he was "keen to learn some biophysics". When he actually got to work, he decided to look at the research from a different perspective — using a biological system for engineering purposes.

His approach was very successful; he talks fondly of the year he spent there working on molecular machines made from DNA. He describes the machines as tweezers with stiff arms seven nanometres long made from double-stranded DNA. Selectively adding complementary strands of DNA can open and close those arms.

Back in Oxford he is building a molecular motor that will move along a track. He is also investigating general strategies for nanostructure fabrication based on molecular recognition of DNA strands. The DNA motors could be used to control self-assembly of microscopic components, for example to create molecular-scale integrated circuits.

Turberfield is now developing an interdisciplinary research programme in collaboration with colleagues in the physical and life sciences departments. His alliance with Lucent is also still strong and his work with them continues. **A. J.**

➧ **http://www-nt.physics.ox.ac.uk/qop**

researchers to commercialize their work, says Saxl, who co-authored the IoN report. But, she adds, Britain's commercial world needs nanotech. The IoN points out that Britain's pharmaceutical sector (which accounts for 6% of world sales and a third of Britain's research and development) and its rapidly growing biotechnology industry are obvious benefactors of nanotechnology research. They would find immediate use for the potential technologies such as nanoparticles in drug delivery.

Technology transfer in nanotechnology can strengthen the United Kingdom's overall economy — especially by funding technologies that can be imported. According to an estimate by the Royal Academy of Engineering, around 60% of all diagnostic and monitoring instrumentation used by the National Health Service originates in other countries.

Saxl believes that Britain can learn to accelerate its technology transfer by looking abroad. The IoN is arranging for a team of key academics from Britain to visit the United States and Germany early next year. Both these countries have already been spending a considerable amount on nanotechnology research. The academics aim to bring back information on nanotechnology policy and how nanotechnology is being successfully applied.

The United Kingdom can also strengthen its nanotech efforts by involving scientists from many different fields, says Adam Curtis, at the Centre for Cell Engineering at Glasgow University. "There is a big opportunity for interdisciplinary research — electrical engineers, chemists and biologists will all make up future nanotechnology researchers," he says. The recent joint call for proposals from several of the United Kingdom's research councils indicates that the potential funders are already thinking in this direction. Curtis is part of a consortium bidding for funds to establish two interdisciplinary research centres for nanotechnology.

But George Smith, head of the materials department at the University of Oxford, calls the UK nanotech funding "hopelessly inadequate" compared with funding in other countries. The government's plans for two interdisciplinary centres funded with around £10 million (US$14 million) over five years each pale in comparison with the US National Nanotechnology Initiative, which has a budget of $500 million for 2001 alone. The comparison gives "some idea of the scale of the mountain we have to climb", Smith says. ■

Alok Jha is a reporter in London for *Research Fortnight.*

Institute of Nanotechnology
➧ **http://www.nano.org.uk/**
UK Research Councils
➧ **http://www.research-councils.ac.uk/**
Centre for Cell Engineering, Glasgow University
➧ **http://www.gla.ac.uk/centres/cellengineering**

US industry starts to think big by acting small

Nanotechnology now resembles biotechnology or information technology in their infancies — before venture capital flowed unimpeded, and jobs abounded. But predicting job growth in this developing field is difficult, not least because nanotechnology is more than one thing.

The broadest definition describes nanotechnology as the manipulation of individual molecules smaller than 100 nanometres (although some would argue for 50 nanometres). The concept has sparked scientific imaginations because working at this 'nanoscale' changes the physical properties of materials — making things really small provides researchers with another way to control materials.

That prospect of greater control opens up options in many areas. In materials science, for example, a polymer could be made more durable by mixing it with nanoparticles. Particles fused to pieces of DNA could be made into medical devices to diagnose different diseases. And in nanoelectronics, tiny circuits could be built up molecule by molecule, rather than be etched away using standard lithography techniques.

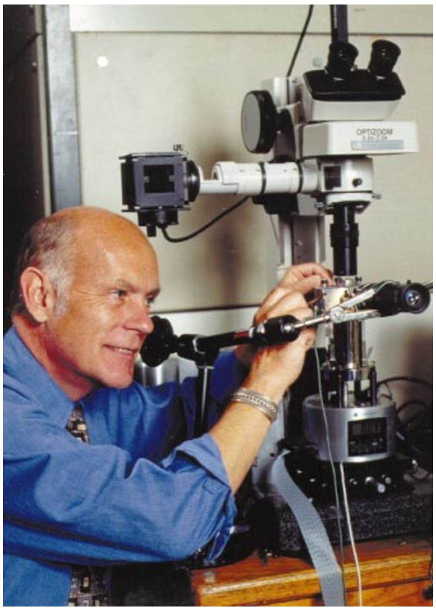
Job prospects in each of these areas will differ. But to jumpstart the opportunities, the US National Science Foundation (NSF) has doubled its budget for nanotechnology research, to about $500 million in 2001.

But this rise must be kept in perspective, says Stanley Williams, director of the Quantum Structures Research Initiative at Hewlett-Packard Laboratories in Palo Alto, California, who wrote a report on nanotechnology with Mihail Roco, programme director of the NSF's nanotechnology initiative. He believes the $250 million increase to be "a drop in the bucket", especially when it is compared with the entire budgets of other US science funding agencies, such as the National Institutes of Health, which has seen recent hikes in excess of $1 billion. He feels that although the initiative will boost the currently low success rate for people applying for NSF grants in nanotechnology, it will still only be able to fund about a fifth of the proposals it receives.

And new jobs will not emerge immediately, Williams adds. "Are there a lot of jobs and do we see a lot of jobs in the next year or so? I would say no," he says. He suspects that nanotechnology will first transform existing jobs. But if the technology proves successful, nanotech jobs could follow the same exponential growth as was seen when information technology and biotechnology took off.

Williams believes materials science is the area likely to benefit first. The field is already ▶

R. SMALLEY



Tubular sells: Richard Smalley hopes to capitalize on nanotubes.

following the biotech model: innovations in universities, followed by spin-off companies, and eventually adaptation by larger firms.

Richard Smalley at Rice University is a case in point. Smalley shared the 1996 Nobel Prize for Chemistry for discovering buckminsterfullerene (C_{60}) — a new form of carbon — and its attendant family of fullerenes. Since then, he has begun manufacturing a tubular version of the carbon macromolecules. He is now set to step up production with his new company, Carbon Nanotechnologies.

Initially, the company will remain small, at around 25 employees. It will focus on producing tubes for researchers who might use them to make polymers, medical devices or to build circuits. The company might eventually try some of those applications on its own. "But right now we just want to make the stuff," says Smalley.

Dow Chemical, on the other hand, is testing the potential of using clay nanoparticles in polymers. The company has a small programme — $16 million over five years, half of which comes from the US National Institute of Standards and Technology — to design plastics that evenly incorporate nanoparticles.

"The target here is to design plastics that have the behaviour of metals," says Juan Garces, a senior research scientist at Dow. He hopes to be able to coax the particles to self-assemble and so disperse evenly into the polymer matrix. Because the clay nanoparticles have a higher ratio of atoms on their surface than do larger clay molecules, he expects the composite formed to withstand higher temperatures than conventional polymers. But expanding this programme so that it generates more jobs relies on more than just scientific success — it must also make money.

Instrumental technology

One application for nanotechnology that is potentially profitable is in medical testing devices, notably those that can read small amounts of DNA. This has attracted university researchers and resulted in a number of spin-offs.

Chad Mirkin, director of Northwestern University's Institute for Nanotechnology incorporated his company, Nanosphere (based in Evanston, Illinois), last January, out of his research on using DNA to aid self-assembly. The company, which has eight employees and is on track to double this figure in a year, aims to produce particles that will bind specifically to minute quantities of DNA, which could then be used as very sensitive probes for disease.

One of the company's staff scientists, James Storhoff, says the company epitomizes how truly multidisciplinary nanotechnology can be. Physical chemists look at the properties of different materials to work out which will make the best nanoparticle for a particular application. Organic chemists then find ways to attach the DNA pieces to the particles. Biologists look primarily at the DNA to find out what sequences would be best for diagnosing particular conditions. And engineers will eventually build a device that scans the particle and identifies the presence of disease.

James Storhoff recognizes the interdisciplinary nature of nanotech.

One of the most talked about areas of nanotechnology holds arguably the greatest promise of long-term job prospects: developing computer chips with ever-smaller circuitry. "Lithography is going to reach a limit," says Thomas Theis, head of physical sciences at IBM's Thomas J. Watson Center in Yorktown, New York.

So instead of carving away at a chip, the next step will be to build circuitry from the ground up, perhaps using DNA to put the switches in place. IBM has probably the largest nanocomputing groups in the world with 40–60 'hardcore' nanotechnology researchers.

IBM built such a large team because the company realized that processing speed and storage space could not keep increasing without a technical shift. The same impetus is driving DuPont iTechnologies, which makes material for integrated circuits, and Agilent, to invest more in basic research.

Agilent is rebuilding its basic research group after splitting with Hewlett-Packard last November. The group functions more like an academic team, and is judged more on publication than on product, says Len Cutler, director of precision instrumentation and basic research at Agilent in Palo Alto. The team now has seven members, but the company would like to double that. Agilent, like so many other companies, is poised to take advantage of the nanotech boom, but remains cautious of investing too much too soon. ■

Paul Smaglik is *Nature*'s correspondent in Washington DC and Careers and Recruitment editor.

National Nanotechnology Initiative
➧ **http://www.nano.gov**

Carbon Nanotechnologies
➧ **http://www.cnanotech.com**

Nanosphere
➧ **http://www.nanosphere-inc.com**

Nanogen
➧ **http://www.nanogen.com/www1/index.htm**

Building for the future

If universities are to be the engines for powering nanotechnology, then new facilities may be the sparkplug. So far only one institution, Rice University, has what Stanley Williams, a senior principal lab scientist at Hewlett-Packard Laboratories in California, calls true nanotechnology capabilities — the resources to produce and analyse materials smaller than 100 nanometres.

But several universities are planning to build such facilities. Harvard's proposal drew Charles Marcus from a tenured position at Stanford, even though the Harvard project has not yet broken ground. Although the National Science Foundation funds several nanofabrication centres, "you have to wait in line", says Marcus.

Northwestern University's Institute for Nanotechnology will get its own $34 million building in 2002. And the University of California at Los Angeles, partnering with the University of California at Santa Barbara, is hoping to receive state funds for a $360 million facility. Williams says the completion of those buildings will coincide with when he expects the job market in nanotechnology to take off — the next five to ten years. Just as biotech companies spun out of the boom of life science research over the past ten years, he expects nanotech companies to emerge from university nanotech programmes as they continue to expand. **P.S.**

Center For Nanoscale Science And Technology at Rice University
➧ **http://cnst.rice.edu**

Northwestern University Institute for Nanotechnology
➧ **http://www.northwestern.edu/research/nanotechnology/index.html**

A compendium of US nanofabrication facilities
➧ **http://deas.harvard.edu/~jones/lab_arch/nano_facilities/nano_facilities.html**