ICSTI IRELAND

Irish Council for Science, Technology and Innovation

ICSTI Statement on

Nanotechnology

Forfás

Established by the Government and Forfás to advise on Science, Technology and Innovation

ICSTI Statement on

Nanotechnology

This Statement was ratified by ICSTI at its meeting in January 2004.

FUNCTIONS OF THE IRISH COUNCIL FOR SCIENCE, TECHNOLOGY AND INNOVATION (ICSTI) ESTABLISHED 1997

- To advise on science, technology and innovation policy-related issues in response to specific requests from the Government (through the Minister responsible for Science and Technology) or from the Board of Forfás;

- To advise the Minister responsible for Science and Technology, the Office of Science and Technology and the Board of Forfás on the Council's own initiative, on policy for science, technology and on related matters;

- To advise the Minister on the strategy for the preparation and implementation of national programmes in science, technology and innovation;

- To advise the Minister on the strategic direction for State investment in science, technology and innovation;

- To undertake, from time to time, such other functions as the Minister may decide.

CONTENTS

CONTENTS

LIST OF APPENDICES

1.0 EXECUTIVE SUMMARY

Knowledge economies across the globe are attempting to understand how best to react to the emergence of nanotechnology as a key enabling technology.

Ireland, as a small open knowledge-based economy, also needs to understand how best to react to this development.

Recognising this need, the Irish Council for Science, Technology and Innovation established a Nanotechnology Task Force.

The role of the Nanotechnology Task Force was to bring together the stakeholders to facilitate the development of a common vision and strategy for nanotechnology in Ireland.

The stakeholders included relevant government departments, their agencies, professional research organisations, indigenous and multinational industry and the wider community.

The resulting vision and strategy was based on an analysis of major global trends and the needs of Ireland as a small open knowledge-economy.

In this context the Nanotechnology Task Force identified the following objectives:

- to agree a national nanotechnology definition;
- to agree a national nanotechnology roadmap;
- to understand the general nature of the nanotechnology opportunity for the Irish economy;
- to understand the specific nature of the nanotechnology opportunity for key sectors of the Irish economy;
- to assess the existing national nanotechnology capability;
- to develop a sustainable vision and strategy for nanotechnology in Ireland; and
- to agree on recommendations that will enable the key stakeholders to work together to exploit the nanotechnology opportunity for Ireland.

It should be noted that historical descriptions of the development of the nanoscience and nanoengineering disciplines underpinning nanotechnology and also the emergence of a global market for nanotechnology enabled products and processes are not included in the present report. Detailed descriptions of both are the subjects of numerous existing and excellent reports.

Nanotechnology – National Definition

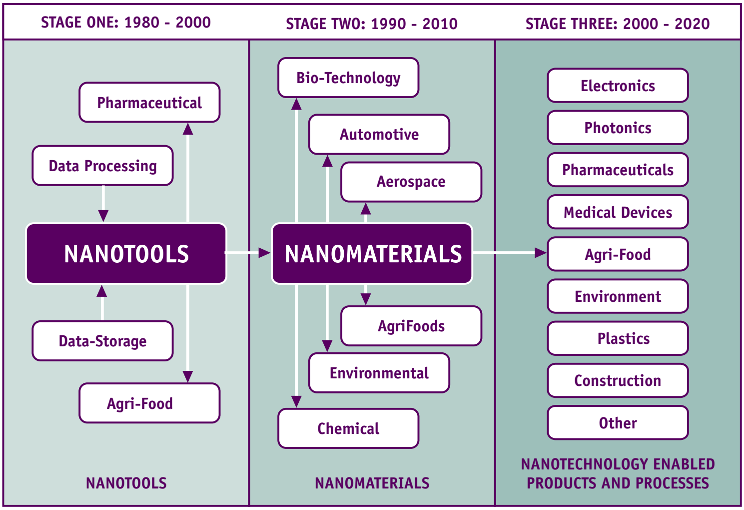
It was agreed that the following national definition of nanotechnology be adopted:

Nanotechnology is a collective term for a set of tools and techniques that permit the atoms and molecules that comprise all matter to be imaged and manipulated. Using these tools and techniques it is possible to exploit the size-dependent properties of materials structured on the sub-100 nanometer scale [1]*, which may be assembled and organised to yield nanodevices and nanosystems that possess new or improved properties. These tools and techniques, materials, devices and systems present companies in all sectors of the Irish economy with opportunities to enhance their competitiveness by developing new and improved products and processes.*

1 *nanometer (nm) = 10^{-9} m, to give an idea of scale, would be around 80,000 times smaller than the diameter of a human hair.*

Nanotechnology – National Roadmap

It was agreed that the following national roadmap for nanotechnology be adopted:



The Roadmap extends from 1980 to 2020 and represents the evolution of nanotechnology in three stages. The first stage, extending from 1980 to 2000, recognises the emergence of a mature and largely consolidated nanotools sector and the existence of a nascent nanomaterials sector.

The second stage, extending from 1990 to 2010, reflects the emergence of a mature and largely consolidated nanomaterials sector and the marketing of a growing number of nanotools and nanomaterials enabled products and processes.

The third stage, extending from 2000 to 2020, foresees the use of nanotools and nanomaterials becoming widespread in many sectors, leading to the commercialisation of new and improved products and processes enabled by the incorporation of nanodevices and nanosystems.

Nanotechnology – National Opportunity

Following extensive consultation, and with particular reference to the evolving economic development strategies of both Enterprise Ireland and the IDA, it was agreed that nanotechnology would significantly impact on the majority of sectors comprising the Irish economy.

The opportunities that arise in all sectors are the following:

- Firstly, the development of the nanotools and nanomaterials necessary to enable new or improved products and processes;
- Secondly, the use of nanotools and nanomaterials to improve performance or reduce cost of existing products and processes; and
- Thirdly, the development and marketing of new products and processes made possible only by use of nanotools and nanomaterials and the nanodevices and nanosystems enabled by them.

In respect of established indigenous companies, it is clear that the greatest opportunity lies in increasing competitiveness by improving the performance or reducing the cost of existing products and processes by using nanotools and incorporating nanomaterials.

In respect of new indigenous companies and multinational companies, it is clear that the greatest opportunity lies in increasing competitiveness by both developing new products and processes and in improving the performance or reducing the cost of existing products and processes by using nanotools and nanomaterials and the nanodevices and nanosystems enabled by them.

It has been predicted that the global markets for nanotechnology-enabled products will grow from an estimated $0.3 trillion in 2002 to $1.0 trillion by 2010.

Assuming that the recommendations of the Task Force are implemented it is conservatively estimated that the value of nanotechnology-enabled products and processes exported by indigenous companies and multinational companies based in Ireland, will exceed €13 billion by 2010, corresponding to more than 10% of the value of all exports in today's terms.

Nanotechnology – Sectoral Opportunities

Having agreed that nanotechnology would impact significantly on the majority of sectors comprising the Irish economy, and having identified the general opportunities that arise in all sectors as a result, the specific opportunities that arise in each of the following sectors were considered:

- ICT – Electronics
- ICT – Photonics
- Healthcare - Pharmaceuticals
- Healthcare – Medical Devices
- Agri-Food
- Polymers and Plastic
- Construction

It was agreed that there are major opportunities for companies of all sizes, both indigenous and multinational, within each of these sectors. It is clear that these sectors have common needs in terms of a national nanotechnology capability. It is also clear, however, that these sectors have different needs that must be met by the national nanotechnology capability on different timescales.

Nanotechnology – National Capability

It is estimated that there are 114 full-time researchers in 10 internationally recognised groups engaged in nanotechnology research in Ireland. These groups have attracted significant funding for facilities (over €30 million) and projects (over €60 million) nationally and internationally in the recent past. These groups are reporting important advances in nanotools and nanomaterials technologies and are training large numbers of professionals, including an estimated 250 postgraduate students, skilled in many aspects of nanotechnology.

These research groups have spun-out two start-ups to date, which have been successful in attracting international venture capital. It is estimated that a further eight companies will be spun-out from these groups in the next five years.

Enterprise Ireland has identified an initial group of 40 companies as potential early adopters of nanotechnology. To date, six of these companies have begun using nanotechnology to improve existing products and processes with several others in the pipeline.

There are currently four Irish-based multinationals developing new products and processes based on nanotechnology. The internationally recognised national nanotechnology research and development capability will help embed these companies and offers the opportunity to attract others.

Nanotechnology – National Strategy

The strategy, at the highest level, is to exploit the general and sector specific nanotechnology opportunities that arise for new and existing indigenous and multinational companies by facilitating the co-operation of the key stakeholders to achieve the following:

- The growth of a number of potentially high value companies spun-out of the relatively large number of internationally recognised nanotechnology groups active nationally.
- A significant increase in the number of established indigenous companies that are using nanotechnology to improve the performance or reduce the cost of existing products and processes to enhance competitiveness.

- A significant increase in the number of multinational companies that are using nanotechnology to improve the performance or reduce the cost of new and existing products and processes; to enhance competitiveness, with the additional benefit of embedding existing and attracting new foreign direct investment.
- The coordination of the funding of fundamental and applied nanotechnology research in third level institutions with a view to ensuring the necessary supply of skilled professionals; and with a view to building on the Ireland's broad-based nanotechnology activity to enable key sectors to exploit specific nanotechnology opportunities.
- The promotion of informed consideration by the wider community of the opportunities and challenges presented by nanotechnology, with a view to transparent regulation that attracts the support of all.
- The promotion of Ireland as a leading nanotechnology location internationally

The Establishment of a National Nanotechnology Forum will facilitate co-operation between academia, industry and funding agencies and promote Ireland as an effective cluster.

Nanotechnology – Recommendations

In the context of the above strategy, we recommend that:

(i) New Indigenous Companies
Enterprise Ireland continues to support the establishment and growth of indigenous nanotechnology or nanotechnology enabled companies through the mechanisms available to support high-potential start-ups.

(ii) Established Indigenous Companies
The Board of Enterprise Ireland fully implement their recently approved and highly commendable strategy aimed at using nanotechnology to improve the performance and reduce the cost of products and processes marketed by established indigenous companies and, thereby, to improve their competitiveness.

(iii) Multinational Companies
IDA Ireland employs the information contained in this report to further inform existing and potential client companies of the opportunity to establish and develop nanotechnology enabled activities in Ireland and to actively support these projects.

(iv) Research Infrastructure

The relevant agencies co-ordinate funding of the national infrastructure necessary for internationally competitive nanotechnology research and also fund access to this infrastructure.

The relevant agencies co-ordinate funding of internationally competitive nanotechnology research with a view to building on Ireland's position of relative strength internationally and with a view to ensuring maximum return on the national investment.

The relevant funding agencies, research institutions and industry work together to establish thematic clusters focused on meeting strategic nanotechnology needs of key sectors.

Initially, research clusters be established to focus on meeting the specific skills and nanotechnology needs of the ICT and Healthcare sectors. These areas are prioritised on the basis of the potential return on investment, specifically the impact on and growth of export earnings.

(v) The Wider Community

The relevant government agencies bring together the representatives of research institutions and companies and the representatives of other government agencies and non-governmental organisations to ensure that the opportunities and challenges presented by nanotechnology are transparently exploited in a responsible and regulated manner that gains support from the wider community.

(vi) Profile

All stakeholders work together to promote Ireland internationally as a centre of excellence in nanotechnology.

(vii) National Nanotechnology Forum

A National Nanotechnology Forum is established to facilitate ongoing co-operation between the stakeholders and to ensure coherence in the national approach to nanotechnology and the opportunity it represents.

2.0 INTRODUCTION

2.1 Background

For some nanotechnology is one of three key enabling technologies that, together with information and communication technology (ICT) and biotechnology, will underpin important innovations and enhance our quality of life.

For others, it is yet another example of a worrying trend among modern scientists and engineers to hype their findings and to do so by 'repackaging' existing and long-established scientific and engineering disciplines.

Whatever your view, it is clear that very significant and rapidly growing funding is being allocated to research and development under the banner of nanotechnology by agencies in the US, Europe and Japan.

It is also clear that the leading early stage venture capital companies and institutional investors in the US, Europe and Japan have identified nanotechnology as a potentially important opportunity and are investing heavily in a growing number of start-ups and established companies.

Many leading multinational corporations have established internal groups to examine the 'nanotechnology opportunity'. In some cases these groups have gone on to exploit identified opportunities by establishing 'in-house' or 'spun-out' start-ups, or by acquiring stakes in existing start-ups.

2.2 Irish Council for Science Technology and Innovation

It was against this background that the Irish Council for Science Technology and Innovation (ICSTI) established a Nanotechnology Task Force.

The role of this Task Force was to bring together the key stakeholders to facilitate the development of a common vision and strategy for nanotechnology in Ireland.

The key stakeholders include relevant government departments, their agencies, professional research organisations, indigenous and multinational industry and the wider community.

The resulting vision and strategy is based on an analysis of the global context and the needs of Ireland as a small open knowledge-economy.

2.3 Nanotechnology Task Force

The Task Force, having considered the global context and having consulted nationally and internationally, identified the following objectives:

- to agree a national nanotechnology definition;
- to agree a national nanotechnology roadmap;
- to understand the general nature of the nanotechnology opportunity for the Irish economy;
- to understand the specific nature of the nanotechnology opportunity for key sectors of the Irish economy;
- to assess the existing national nanotechnology capability;
- to develop a sustainable vision and strategy for nanotechnology in Ireland; and
- to agree on recommendations that will enable the key stakeholders to work together to exploit the nanotechnology opportunity for Ireland.

2.4 Structure and Scope of Report

The report that follows contains chapters detailing how the Task Force has achieved each of the above objectives. The supporting material for the report is contained in the relevant Appendices.

It should be noted that a detailed description of the historical development of the nanoscience and nanoengineering disciplines underpinning nanotechnology is not included in the present report.

It should also be noted that a detailed description of the emergence of a global market for nanotechnology enabled products and processes is not included in the present report.

Detailed descriptions of both are available in numerous reports available from reliable sources in **Appendix I.**

2.5 Acknowledgements

The Council wishes to express its gratitude to the Members of the Task Force, and to the stakeholder organisations they represented, for their contribution to the preparation of this report.

The Council wishes to thank the national and international experts who acted as Members of the Sectoral Roadmap and International Benchmarking Panels.

Council thanks are also extended to the many other individuals and stakeholder organisations that participated in the Consultative Workshops.

Finally, the Council gratefully acknowledges the work of Mr. Colm Reilly and his colleagues from PA Consulting, who assisted the Task Force throughout.

All of these individuals are listed in **Appendix II.**

3.0 NANOTECHNOLOGY

3.1 Definition

Following extensive consultation; and with reference to international best practice, it was agreed the following national definition of nanotechnology be adopted:

Nanotechnology is a collective term for a set of tools and techniques that permit the atoms and molecules that comprise all matter to be imaged and manipulated. Using these tools and techniques it is possible to exploit the size-dependent properties of materials structured on the sub-100 nanometer scale, which may be assembled and organised to yield nanodevices and nanosystems that possess new or improved properties. These tools and techniques, materials, devices and systems present companies in all sectors of the Irish economy with opportunities to enhance their competitiveness by developing new and improved products and processes.

[One nanometer (1 nm = 10^{-9} m), to give an idea of scale, would be around 80,000 times smaller than the diameter of a human hair.]

To place the above definition in a global context, we have included as **Appendix III** definitions currently in use in the United States of America, Japan and the European Union.

3.2 Illustration

A number of applications of nanotechnology are discussed in order to illustrate the terms used in the above definition.

The last decade has seen the emergence of a consolidated global sector supplying a growing number of inexpensive and reliable nanotools to scientists and engineers in academia and industry. Using these nanotools it is possible to image and manipulate the individual atoms and molecules that make up all matter.

One such nanotool is the Scanning Tunnelling Microscope (STM). This tool uses a conducting tip to probe the surface. Briefly, the conducting tip is held close to the conducting surface to be imaged, and electrons flow between the tip and surface. The tip is very sharp, ideally being formed by a single atom. The tip is raised and lowered as it scans across the surface to keep the current flowing between the tip and the surface constant. This also keeps the distance between the tip and the surface constant. By plotting the vertical movement of the tip as a function of position, an atomically resolved image of a surface can be generated. Rohrer and Binnig were awarded the 1986 Nobel Prize for their work in developing this nanotool.

Using scanning tunnelling microscopy it is possible to resolve and manipulate individual atoms that are present at the surface of a metal. The consecutive images shown below in Figure 3.1, from the Boland Group at Trinity College Dublin, show the manipulation of a single hydrogen atom (white spots) on a silicon surface using the probe tip of a STM.

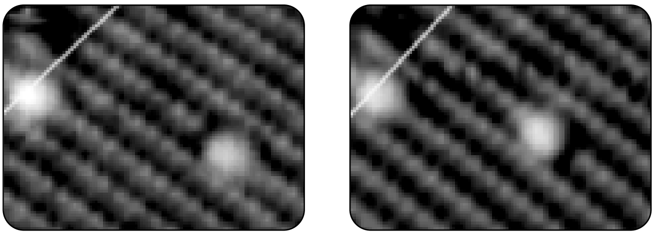


***Figure 3.1:** Manipulation of Hydrogen atoms on a silicon surface.*

A whole family of related nanotools, including Atomic Force Microspcopes (AFM) and Scanning Near-Field Optical Microscopes (SNOM), has since been developed.

In the manipulation sequence shown in Figure 3.2, a 13 µm long and 50 nm wide nanowire is pushed along the substrate surface by using AFM[2]. The wire diameter is approximately 1/1000 of the diameter of a human hair and even its length is still only 1/4 of the diameter of a human hair.

2 micrometer (µm) = 10^{-6} m.

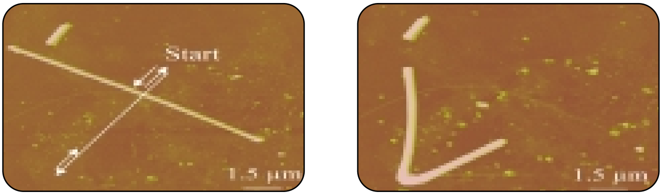


Figure 3.2: *Manipulation of a nanowire.*

It is important to note that many of the most important nanotools have been developed by the semiconductor industry. These tools are still principally used in the fabrication of data storage and processing technologies, but are increasingly finding applications in other areas.

The availability of such tools is allowing new insights in to how to control and exploit the, sometimes novel, properties of materials and structures at the nanometer scale.

A particularly active area of research, in both academia and industry, has been the preparation of nanoparticles (1 nm to 100 nm in diameter) of a very wide range of materials. These can be prepared using techniques that result in the formation of nanoparticles that are virtually identical in size and shape.

For example it is possible, as shown in Figure 3.3, to prepare nanocrystals of the semiconductor cadmium selenide (CdSe) that are between 1 nm and 100 nm in diameter. The smallest nanocrystals have properties that are very different from the bulk semiconductor, while the largest have properties that are similar to those of the bulk semiconductor. One property that is characteristic of a semiconductor is its bandgap energy. By tuning the size of the CdSe nanocrystals it is possible to tune the bandgap energy and, as a consequence, the colour of the nanocrystals themselves. This level of rational control over the properties of materials is unprecedented. These nanocrystals are already finding applications in next-generation biological markers.

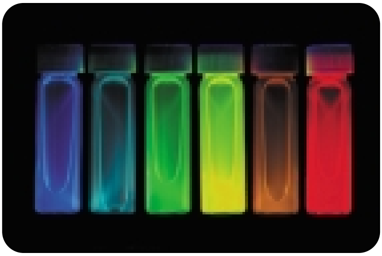


Figure 3.3: *Nanocrystals of the semiconductor CdSe.*

Bawendi and co-workers[3], who first described the preparation of the CdSe nanocrystals, as shown in Figure 3.3, have recently described the assembly and organisation of these nanocrystals to produce the nanodevices shown in Figure 3.4. Specifically, light emitters for next-generation displays and lasers.

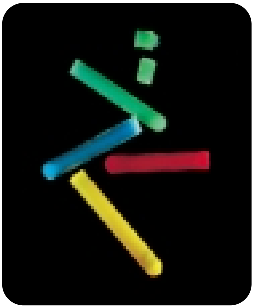


Figure 3.4: *CdSe nanocrystal can be assembled to produce nanodevices, such as next generation light emitting displays and lasers. (Copyright Felice Frankel from Envisioning Science, The Design and Craft of the Science)*

There are a growing number of products and processes that have been improved or even made possible only by the use of nanotools and the incorporation of nanomaterials. These include products as diverse as paper-quality displays and self-cleaning windows.

NTERA Ltd., an Irish company, has developed and is manufacturing paper quality displays which are electrochromic displays that have the characteristics of ink on paper. The design and manufacture of these displays shown in Figure 3.5, is made possible by the incorporation of novel nanostructured film technology developed at University College Dublin.

[3] *Murray CB, Kagan CR, Bawendi MG, Annual Review of Material Science, 30, 545-610, 2000.*

Figure 3.5: *Electrochromic displays developed by NTERA with ink-on-paper qualities.*

In the case of Intel, an Irish-based multinational company, the construction of FAB 24 just outside Dublin is nearing completion. This fabrication facility will manufacture integrated circuits, which possess sub-90 nanometer features, using state-of-the-art nanotools and nanomaterials. This will be the most advanced commercial nanotechnology location in the world.

There have been a vast number of reports published in the past few years providing detailed descriptions of available nanotools and nanomaterials, and describing products and processes enabled by these tools and materials. A selected list of reports is provided for further reading **(Appendix I).**

3.3 Scope of Definition

In defining nanotechnology as we have done, we have focused on those aspects of nanotechnology, which are or will be commercially important over the next ten years in the Irish context.

An implication of the above decision is that the agreed national nanotechnology definition will need to be re-examined periodically in light of major technology and market developments and the need for Ireland to maintain competitiveness.

4.0 ROADMAP

4.1 Background

The nanotechnology roadmap represents a distillation of existing reports (Appendix I) and the outcome of extensive consultations with representatives of the key national and international stakeholders at a series of sector workshops. The map is shown in Figure 4.1, page 27.

The Roadmap extends from 1980 to 2020 and represents the evolution of nanotechnology in three stages. The first stage, extending from 1980 to 2000, recognises the emergence of a mature and largely consolidated nanotools sector and the existence of a nascent nanomaterials sector.

The second stage, extending from 1990 to 2010 reflects the emergence of a mature and largely consolidated nanomaterials sector and the marketing of a growing number of nanotools and nanomaterials enabled products and processes.

The third stage, extending from 2000 to 2020, foresees the use of nanotools and nanomaterials becoming widespread in many sectors, leading to the commercialisation of new and improved products and processes enabled by the incorporation of nanodevices and nanosystems.

It should be noted that these stages refer to the development of a mature sector, driven by the availability of reliable and inexpensive product offerings from established competitors.

It should also be noted that representing these stages as part of a linear roadmap does not in some respects reflect the true complexity of the situation.

4.2 Nanotools

The last decade has seen the emergence of a developed and largely consolidated nanotools sector dominated now by a number of major players, each offering a growing range of inexpensive and reliable tools.

New and innovative tools continue to be brought to the market by these major players, in an effort to meet the present and future needs of the electronics sector as defined by that sectors own technology roadmaps for data processor and storage technologies. This continues to represent a major driver for the nanotools sector.

Increasingly, however, a major driver for the mature sector is to provide research tools for a growing number of scientists and engineers in academia an industry. It is clear, for example, that in the agri-food sector researchers based in academia and industry are increasingly driven by the desire to understand the relationship between the structure on the nanometer scale of the materials that constitute food products and their function and consumer acceptance.

4.3 Nanomaterials

We are now seeing the emergence of a mature nanomaterials sector. At present this sector consists of a large number of small start-ups, often spun-out from research groups based in academia, and a large number of new business units within the established fine chemicals and materials companies.

Generally, these start-ups are built around a new class of proprietary nanomaterials possessing novel properties which, it is expected, will meet a need that conventional materials do not.

The new business units, however, are looking to adapt existing materials or processes to meet the growing demand for nanomaterials from existing or new customers. These new business units are also seeking to identify research groups based in academia and high-potential start-ups with which they can establish a close working relationship.

It is likely that many start-ups will not survive as nanomaterials become a commodity or, even if successful, will be acquired by established fine chemicals and materials companies, seeking to grow their share of this emerging market by combining new proprietary nanomaterials with their established production capabilities and channels to market. This is likely to lead to a consolidation of this sector.

4.4 Nanotechnology Enabled Products and Processes

The emergence of mature nanotools and nanomaterials sectors, and the availability of the nanodevices and nanosystems they enable, is seen as a necessary prerequisite for the widespread adoption of nanotechnology by companies in all sectors and the development of new or improved nanotechnology enabled products that enhance or maintain competitiveness.

It is believed that leading companies in sectors characterised by the early adoption of technologies, for example the electronics and medical devices sectors, will exploit the potential offered by nanotechnology by developing 'in-house' capability and by partnering with leading researchers in academia and the nanotools and nanomaterials sectors.

However, for following companies in these sectors and for companies in sectors not characterised by the early adoption of technology, it is believed that the emergence of mature nanotools and nanomaterials sectors is a prerequisite to widespread exploitation.

4.5 Conclusions

As stated, the nanotechnology roadmap shown in Figure 4.1 represents a distillation of existing reports and the outcome of extensive consultations with representatives of the key national and international stakeholders.

This roadmap will be used as the basis of the analysis of the opportunities that exist, now and in the future, for both new and established indigenous and multinational companies in Ireland.

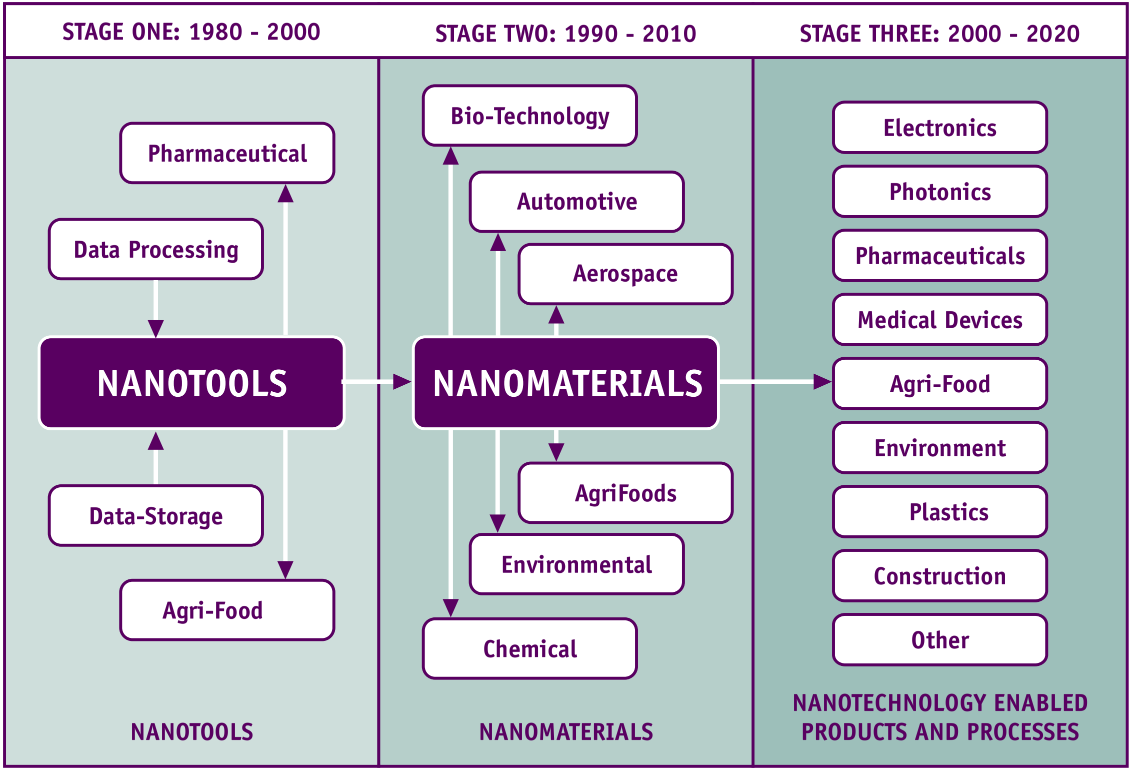


Figure 4.1: *National Roadmap for Nanotechnology 1980–2020.*

5.0 OPPORTUNITY

5.1 Background

In this section of the report we consider the following global and local opportunities, which arise as a result of the emergence of nanotechnology as a key enabling technology:

- to provide the nanotools and nanomaterials that will be needed by scientists and engineers in academia and industry;
- to improve existing products and processes by enhancing their performance and reducing their cost;
- to develop new products and processes that address a previously unmet need.

We will consider the potential impact of each of these opportunities in both the global and local contexts.

5.2 Nanotools and Nanomaterials

There exists a mature and largely consolidated nanotools sector that supplies a wide range of nanotools to scientists and engineers working in academia and industry. Many of these tools were originally developed by or for the electronics sector to optimise and control their key manufacturing processes. Increasingly, however, nanotools are being developed specifically for other sectors.

An example of such a nanotool company is Deerac Fluidics™ based in Ireland[4]. This company develops, manufactures and markets a nanotool used to rapidly dispense nanolitre volumes of a liquid (see Figure 5.1). This nanotool addresses an unmet need, for example, in the pharmaceutical sector for a device that can rapidly dispense very small volumes of a drug solution for testing.

There is an emerging nanomaterials sector that will supply a wide range of nanomaterials to scientists and engineers working in academia and industry. These materials are endowed with novel properties as a consequence of their nanoscale dimensions.

[4] *Deerac Fluidics is the registered trading name of Allegro Technologies Limited*

Currently, this sector is comprised of a large number of start-ups, spun-out from leading academic research groups, and a growing number of new business units within the materials and fine chemicals multinationals.

While the number of nanotools and nanomaterials companies, indigenous or multinational, currently based in Ireland is relatively small; the Task Force is aware of a significant number of individuals and groups seeking funding to establish start-ups in this area, and a number of multinational companies seeking to locate in Ireland. For reasons of commercial confidentiality, it is not possible to describe these opportunities in more details.

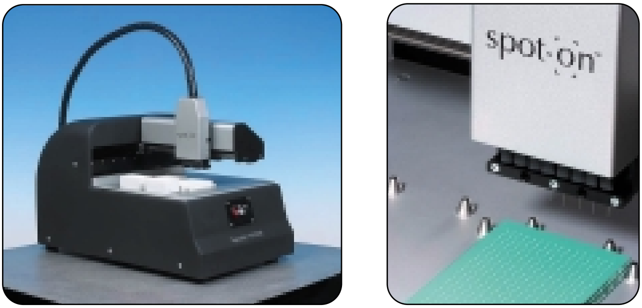


Figure 5.1: *Deerac Fluidics™ spot-on™ technology allows liquid handling in the 20 nanolitre to 2 microlitre range.*

Deerac Fluidics™ has developed an innovative liquid handling technology designed to have a broad range of applications. The proprietary spot-on™ technology allows for the deposition of a wide range of 20 nL to 20 µL.

This product has been developed to meet a strong market drive in the pharmaceutical, biotechnology and analytical sectors towards miniaturisation, the use of smaller volumes of reagents and biological materials.

The driving forces for this shift are two fold. Firstly the reduction of operating costs by lowering the volume of expensive reagents and secondly reducing product development schedules. Deerac Fluidics is supplying an enabling solution to address this need and has developed a global market leading business in the genomics and proteomics areas.

5.3 Improved Products and Processes

There exists a large and rapidly growing number of products and process that have been or that are capable of being improved by utilising nanotools or incorporating nanomaterials.

Nanotools are increasingly being used to establish the relationship between the structure of the materials used to manufacture a product and the performance and cost of the product. They are also increasingly being used to optimise and control the processes that are used to manufacture the above products. In the case of small companies, these nanotools are often accessed, at least initially, through national or regional centres linked to third level institutions or national laboratories.

Nanomaterials, possessing novel properties, are increasingly being used to improve the performance and reduce the cost of a product. Such materials include nanoparticles, nanofilms and nanocomposites of organic (drugs and biopolymers) and inorganic (metal and ceramic) materials. In the future, the assembly and organisation of nanomaterials to yield nanodevices and nanosystems possessing increasingly complex functions will be important. Examples of improved products and processes include secure printing inks (nanoparticle), self-cleaning windows (nanostructured film) and harder wearing tyres (nanocomposite).

For a company to use nanotools and nanomaterials to improve its existing products and processes it will be necessary that the above tools and materials are readily available from a reputable commercial source. It will generally be the case that a company's manufacturing process will be readily adapted to accommodate the use of the above nanotools and nanomaterials.

It is expected that the investment in improving a product or process will be recovered in the form of maintained or improved market share. Increased margins may, however, be quickly eroded by the competitive response; unless, the initial competitive advantage can be maintained by establishing ownership of the relevant intellectual property.

An example of a company that has improved an existing product through developing a proprietary nanocomposite is General Motors, the world's largest vehicle manufacturer (see Figure 5.2). In 2002 GM introduced an advanced thermoplastic olefin nanocomposite step on their mid size vans, to assist occupants in stepping into and out of the vehicle. This was the first automotive exterior application of this high performance and affordable material which was developed in partnership with Basell, the world's largest producer of polypropylene resins for plastics; and Southern Clay Products, Inc. of Gonzales, Texas, which mines and processes the ultrapure "smectite" clay additive. The parts are moulded by Blackhawk Automotive Plastics Inc. of Mason Ohio. GM, Basell and Southern Clay have an agreement that grants mutual confidentiality, which was hitherto unprecedented in GM's relationship with outside suppliers. Basell has an exclusive license on GM's proprietary process to manufacture the material helping to safeguard their research investment. On a volume basis, parts made of nanocomposites cost about as much as parts made from conventional materials because less material is needed to manufacture them and they are stronger and lighter and less brittle in cold temperatures. An added advantage is that no new tooling is necessary to mold the nanocomposite parts. GM and Basell also expect the price to improve as nanocomposites become more widely applied.

This opportunity is available to all small and large companies and, in particular, is available to all indigenous companies in Ireland. There is clearly a role for research and development groups based in publicly funded professional research organisations to support indigenous companies in this respect.

Figure 5.2: *The launch of vehicles by GM incorporating a thermoplastic nanocomposite step to assist entry and exit from the vehicle. Step-assist is the first automotive exterior application of this lightweight, high performance and affordable material.*

General Motors (GM), the world's largest vehicle manufacturer, designs, builds and markets cars and trucks worldwide.

In 2002 GM launched its first vehicles incorporating a nanocomposite step-assist, a thermoplastic olefin nanocomposite part that assists occupants in stepping into and out of the vehicle.

Thermoplastic nanocomposites are made by introducing nanoparticles of a solid material into a plastic resin to give it added strength and other advantageous properties.

The nanoparticle additives have huge surface areas relative to conventional additives to interact with the polymer matrix, and result in composites with exceptional properties with only a fraction of the added material.

GM believes that strong, lightweight nanocomposites are the future of automotive plastics.

5.4 New Products and Processes

There exists a small but growing number of new products and process that have been uniquely enabled by utilising nanotools or nanomaterials.

Examples of new products and processes include delivery of insoluble drugs (nanoparticles), paper-quality displays (nanostructured films) and plastic electronics (composites).

For a company to use nanotools and nanomaterials to develop new products and processes it will be necessary to be a developer or early adopter of the above tools and materials, possibly in prototype form. It will generally be the case that a company's manufacturing process will need to be extensively redesigned or replaced completely.

It is expected that the investment in developing a new product or process will be recovered in the form of a large share of an existing or new market. Generally, it will be possible to maintain a large market share because the associated intellectual property will have been protected.

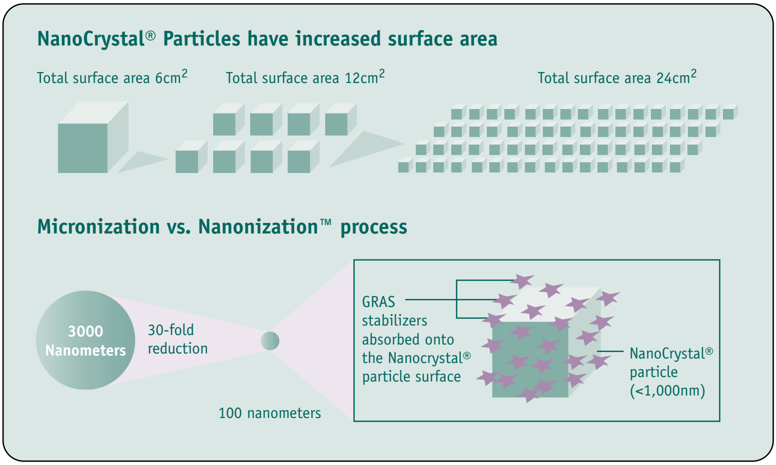


Figure 5.3: *Elan's nanotechnology enabled drug delivery platform, NanoCrystal™ Technology.*

Elan is a pharmaceutical company based in Ireland that has been among the earliest adopters of nanotechnology in the sector.

Elan realised that a growing challenge facing the sector was the inherently poor solubility in water of the increasingly larger molecules used as drugs.

However they also realised that if these drugs were formulated as nanocrystals of less than about 400 nm in diameter; the surface area of these crystals would be so great that they would dissolve at a rate that would ensure that there was enough of the drug in the patient's body to benefit the patient.

For this reason Elan has invested significantly in developing fully approved laboratory and plant processes for formulating poorly soluble drugs as nanocrystals.

This nanotechnology enabled drug delivery platform is already established as one of the most important advances in in drug technology delivery technology in recent times.

An example of a multinational company based in Ireland that has developed a new product and associated process is Elan (see Figure 5.3). This company has developed a range of drug formulations based on nanoparticles, which ensure that otherwise poorly soluble drugs are present in the body at sufficiently high concentrations to benefit the patient. This company has also developed an associated manufacturing process that meets all the requirements of the regulatory authorities. There are currently more drugs in development with this platform technology than with any other in the sector.

This opportunity is available to small and large companies capable of developing or quickly adopting nanotechnologies; in particular, this opportunity is available to the small number of indigenous start-ups spun-out from research institutions, and to some multinational companies in Ireland.

5.5 Potential Markets

Estimates of the size of the nanotechnology market vary widely. This is, in part, due to the fact that the sizes of emerging markets are intrinsically difficult to estimate and, in part, due to the fact that there is no agreed basis on which the size of this market should be estimated.

What the above estimates of the nanotechnology market do generally refer to, are the global size of all those markets in which nanotechnology enabled products and processes are present, that is products manufactured using nanotools or incorporating nanomaterials. What these estimates of the nanotechnology market generally do not refer to, are the sizes of the markets for specific nanotechnologies.

The National Science Foundation in the United States, for example, has estimated that the global nanotechnology market will exceed $1 trillion by 2010. When asked to qualify this often quoted value, it was qualified as including the global markets for all goods and services enabled in whole or in part by nanotechnology. On this basis the estimate may well prove to be on the conservative side.

According to Deutsch Bank, however, the market for nanomaterials alone was $0.12 trillion in 2002, with this market growing at an annual rate of 15% to $0.37 trillion by 2010. A similar estimate for the size of the nanotools market is not currently available.

On this basis it is clear that the markets for nanotools and nanomaterials that can be addressed by new or established indigenous or Irish-based multinational companies are large and growing.

It is also clear that the markets for products and processes, by nanotools or nanomaterials, which can be addressed by new or established indigenous and Irish-based multinational companies, are very large and growing.

For example a recent analysis of the medical devices market, by the Department of Trade and Industry in the United Kingdom, has concluded that at present 1% of all medical devices are nanotechnology-enabled. It has also estimated that this percentage will double every two years for the foreseeable future.

On this basis, the estimates of the Task Force are that the values of nanotechnology-enabled products exported by the medical devices sector in Ireland will grow to €0.6 billion by 2010 in today's terms. It is similarly estimated that the value of nanotechnology-enabled products exported by the pharmaceutical sector will exceed €6.1 billion by 2010 also in today's terms. An analysis of the electronics and photonics sectors suggests that €4.5 billion of all exports in 2010 will be nanotechnology-enabled.

A consensus estimate (reached by the Taskforce) is that the value of nanotechnology-enabled products and processes exported by indigenous companies and multinational companies based in Ireland, will exceed €13 billion by 2010 and correspond to more than 10% of the value of all exports in today's terms.

5.6 Conclusions

Based on the above analysis, one concludes that for established indigenous companies the opportunity lies in using commercially available nanotools and nanomaterials to increase competitiveness by improving existing products or processes. The short-term objective will be to maintain or improve existing market share. Securing intellectual property rights to the improvements introduced may increase the likelihood of a successful outcome.

One also concludes that for new indigenous and local multinational companies that the opportunity lies in the early development or adoption of prototype nanotools, nanomaterials, nanodevices and nanosystems to develop new products and processes. The medium-term objective will be to enter the market first and to establish a large market share protected by extensive intellectual property rights.

6.0 SECTORAL ANALYSIS

6.1 Background

In the previous chapter we identified in general terms the nature of the opportunities that exist for indigenous and multinational companies based in Ireland.

Briefly, it was concluded for indigenous start-ups and local multinationals that the principal opportunity lies in the development or early adoption of nanotools, nanomaterials, nanodevices and nanosystems to develop new products and processes. It was concluded for established indigenous companies that the principal opportunity lies in using commercially available nanotools and nanomaterials to improve existing products or processes.

In order that clear and effective recommendations can be made that will allow the above opportunities to be fully exploited, the specific opportunities that arise in the following key sectors comprising the Irish economy were considered in greater detail:

- ICT - electronics
- ICT - photonics
- Healthcare - pharmaceuticals
- Healthcare - medical devices
- Agri-food
- Polymers and Plastics
- Construction

The first four sectors are dominated by indigenous start-ups and multinational companies, while the last three sectors are dominated by established indigenous companies.

The approach adopted was to overlay the nanotechnology roadmap described in Chapter Four, on the accepted technology roadmap for the sector in question. The points of intersection of the two roadmaps were identified and the nature of the opportunities that arise considered.

The above work for each sector was undertaken by a sub-group comprised of two members of the Task Force and two sector representatives; one academic and one industrial, one national and one international. In all cases the sector representatives were senior individuals responsible for identifying or exploiting nanotechnology opportunities within their own organisations.

6.2 ICT-Electronics Sector

6.2.1 Overview

The electronics sector is characterised by rapid change and by an enviable track record of overcoming major technical barriers to progress, while continuing to deliver very significant improvements in performance and reductions in cost to its customers.

These improvements in performance and reductions in cost are a consequence of the sector's historical ability to exponentially decrease, or 'scale', the minimum feature sizes of the components comprising processor and storage devices.

The new Intel facility in Ireland, for example, will manufacture chips with feature sizes of less than 90 nm and represents a major concentration (in world terms) of working nanotechnologists.

Some of the key challenges currently faced by the sector are listed below

Table 6.1: *Electronic challenges currently being faced by the ICT Sector.*

Electronics Challenges

- Need to maintain a technology leadership.
- Need to develop applications that meet customer needs.
- Need to manage risk and cost in an explicit manner.
- Need to follow a 10-year roadmap that balances leadership, cost and risk.
- The key focus areas for the next 10 years in electronics will be:
  - Aggressive device scaling
  - New device structures
  - New materials
  - New tools
  - Power management

6.2.2 Sector Roadmap

The International Technology Roadmap for Semiconductors (ITRS), a publication of the semiconductor industry associations, charts future developments in the sector **(http://public.itrs.net/).**

A basic premise of the roadmap has been that continued scaling of microelectronics would further reduce the cost per function (averaging roughly 25% per year) and promote market growth for integrated circuits (averaging roughly 17% per year).

The principal purpose of the roadmap is to ensure that the entire supply chain of the industry knows which tools and materials to supply.

There is a high degree of confidence in this roadmap up to the year 2016. However, traditional scaling is beginning to expose the fundamental physical and technological limits of the materials and processes comprising the classical planar silicon (CMOS) technology.

These limits may reduce the rate of progress for conventional CMOS technology before 2016 and may lower the entry barrier for "non-classical CMOS" and alternative device concepts; for example, several companies (Motorola, Intel, ST) are developing nanocrystal-based flash memory devices.

One of the key challenges facing the industry through 2007 and beyond is the development and integration of new materials and fabrication processes whose properties meet the increasingly stringent requirements imposed by shrinking CMOS feature sizes, see Table 6.2.

Year of Production	2002	2004	2006	2007	2010	2013	2016
DRAM half-pitch (nm)	115	90	70	65	45	32	22
MPU/ASIC Half-pitch (nm)	130	90	70	65	45	32	22
MPU physical gate length (nm)	53	37	28	25	18	13	9
ASIC/low power physical gate length (nm)	75	53	37	32	22	16	11

Table 6.2: *Predicted scaling of feature sizes in integrated circuit (IC) technology for Dynamic Random Access Memory (DRAM), Microprocessors (MPU) and application-specific IC (ASIC) product generations in the near term (2002-2007) and long term (2008-2016). Source: ITRS 2002 update; http://public.itrs.net/Files /2002Update/2002Update.pdf*

6.2.3 Intersection with the Nanotechnology Roadmap

Nanotools: The electronics sector had developed and commercialised tools for the manufacture of nanoscale devices long before the nanotools sector had matured. Consequently, the emergence of a mature global nanotools sector is not a key driver.

Nanomaterials: The following key nanomaterials challenges have been identified by the ITRS as device dimensions reach the nanoscale (in one or more dimensions):

- Low κ (dielectric constant) materials for insulation of interconnects, e.g. nanoporous materials.
- High κ materials for 1-3 nm thick transistor gate oxide layers.

Controlling the structure of new and existing materials on the nanometre scale in more than one dimension will be central to delivering these innovations.

Nanotechnology-enabled Products and Processes: Concerning products or processes, the impact of nanotechnology is that it will enable the sector to stay on or surpass its own roadmap.

The current roadmap extends to 2016 and to a gate length of 10 nm (possibly on a 450 mm wafer with a three-dimensional architecture). There is a possibility that processors at this node will require active cooling. Alongside the successful introduction of extreme ultraviolet sources (EUV) and other fabrication processes and tools, the development of innovative materials (high κ, low κ, thermoelectric others) is foreseen and represent critical success factors.

Clearly then, with respect to nanotechnology, the electronics sector will be an early adopter and a most effective exponent of fundamental nanoscale science research and related nanoscale technology development.

6.2.4 Opportunities for Ireland

There is an opportunity for Ireland to develop a comprehensive innovation loop for novel materials that have been identified by the sector as critical to achieving the goals in the ITRS roadmap. This loop would include:

- Design and simulation of materials;
- Synthesis, growth, deposition and processing of materials;
- High-throughput characterisation and analysis;
- Device prototyping, integration and analysis.

Ireland can foster development in this high-impact area, which has relatively low barriers to entry. This development can be used to stimulate indigenous industry and to anchor multinational manufacturers and their suppliers.

To successfully exploit this opportunity, Ireland will need to develop the associated intellectual property and technology transfer infrastructure, which will ensure these materials are available to the sector as and when required by the roadmap.

Ireland should examine its current infrastructure at research institute, agency and industry levels to begin to plan how this aspect of materials research can be developed in the future and to put in place the types of partnerships that would aid its development.

Finally, the development of this activity to address the needs of the healthcare sector is worthy of further investigation.

6.3 ICT-Photonics Sector

6.3.1 Sector Overview

The photonics sector is relatively new and exists to market technologies that use light to transmit, process and store information.

The sector grew out of fundamental research in the 1970s, with the first significant commercial developments in the early 1990s.

Photonics enabled the DotCom boom, where demand for high-speed, high-density optical communication soared. In turn, the DotCom boom fuelled unprecedented growth in photonics industry.

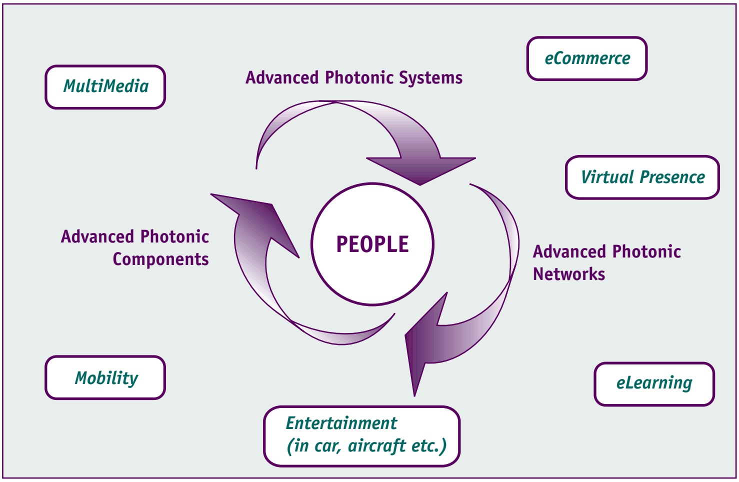


Figure 6.1: *Applications which have been enabled by photonics.*

Growth will continue to be driven, in large part, by the telecommunications sector's extension of existing networks to each individual user's home or office, see Figure 6.1.

Delivering significant cost reductions will be especially important for components enabling access and metro applications, which are more cost-sensitive than the long-haul sector.

Low manufacturing productivity represents a key technical challenge and a barrier to significant cost reductions. This is linked to the fact that there is, as yet, no common scalable manufacturing platform.

6.3.2 Sector Roadmap

Recent decades have seen rapid growth of this sector. Much of this growth has been driven by the telecommunications sector, where photonics technologies have enabled a revolution in data transmission.

In the future, however, growth will also be driven by applications of photonics technologies outside the telecommunications sectors, see Table 6.3 below.

Table 6.3: *Sectors in which photonics have made a significant impact.*

Photonics in Telecommunications	Other Applications of Photonics
The impact of photonic technologies in the field of telecommunications is significant. From the viewpoint of technical performance, key issues include the mix of TDM/WDM, wide bandwidth optical amplifiers, dispersion and polarization management, optical regenerators and the optical processing of IP headers. The key future challenges and issues include: end-to-end optical networking, greater flexibility, increased cost-effective penetration of fibre and the seamless convergence of optical networks and access technologies. In general, the enormous capacity of photonic networks makes them a key enabler for 'people-centred ambient intelligence'.	The second major impact area of photonics is for broader applications outside the telecommunications field. New technical advances in LED technologies, covering different parts of the spectrum are making possible a whole new range of uses relating to direct light sources, visualisation (displays), and sensors. The sectors of application are varied, but key areas include consumer electronics (e.g., CD devices, mobile phone displays) and automotive (with applications ranging from light clusters to infra-red sensors, night vision warning, head-up displays and in-car entertainment and management systems).

At the present time the photonics sector faces two principal barriers to growth.

Cost Reduction: The cost equations have changed dramatically in recent years with the collapse of the telecommunications market. The current requirement is that capital equipment should pay for itself within 12 months. The technology impact of this business requirement is a drive towards scalable architectures.

Manufacturing: Typically quality costs money and economies of scale in manufacturing are hard to achieve for photonic components. It is essential that the industry provides higher functionality at volumes that are cost effective in an environment in which the price paid to transmit voice and data is decreasing.

One route to meet this challenge is to develop the optical equivalent of VLSI whereby field-programmable optical components can be produced in sufficiently high volumes to allow for significant economics of scale and reduction in cost.

6.3.3 Intersection with Nanotechnology Roadmap

Nanotools: The photonics sector is similar to the electronics sector in that it has operated on the nanoscale for some time and the sector has developed many of its own nanotools, e.g. atomic layer deposition techniques for fabrication of quantum well and quantum dot devices. Consequently, the emergence of a mature global nanotools sector is not a key driver.

Nanomaterials: The emergence of a global nanomaterials sector could impact significantly on the photonics sector, e.g. through developments in chemically synthesised semiconductor quantum dots with tailored optical properties, see Chapter Three. Controlling the structure of new and existing materials on the nanometre scale will be central to delivering these innovations.

Nanoenabled Products and Processes: Development of nanotools, nanomaterials and nanoenabled products and processes will occur in parallel, e.g. next-generation optoelectronic devices such as quantum dot lasers will be combined with advanced device engineering, made possible by recent developments in photonic crystal waveguides. This inherent complexity reflects the absence, as of yet, of a common scalable manufacturing platform.

6.3.4 Opportunities for Ireland

Ireland has been developing a strong capability in the photonics area over the last 10 years, leading to the recent emergence of the Irish Photonics Association.

The opportunity for Ireland is to establish a deep capability for generating skilled personnel with the ability to develop innovative materials and devices that have been identified by the sector as critical to achieving the goals implied by the roadmap.

In addition to focusing the national effort on those materials and devices identified as important to the sector, it is also essential that associated intellectual property and technology transfer infrastructure be developed.

6.4 Healthcare Sector - Pharmaceuticals

6.4.1 Sector Overview

The pharmaceutical sector is currently evolving rapidly to meet the new challenges presented by a dynamic market. The challenges include: meeting the requirements of regulatory authorities; demands from consumers for safer and more effective drugs; and competition from non-traditional sectors.

In order to counteract the high costs of drug discovery and development, innovations are being sought that reduce the associated risk and time to market. This has led to significant investment in enabling technologies including biotechnology, information and communication technology and nanotechnology. There has also been an increase in partnerships with smaller companies, which are developing innovative technologies that will impact on a particular sector or market.

6.4.2 Sector Roadmap

From a technological perspective, the pharmaceutical sector is driven by the emerging insight that the genetic code of an individual determines their cellular and sub-cellular structure; that this determines how the body of an individual functions in a given environment; and that this allows drugs that act by binding to specific cellular and sub-cellular structures in the body be rationally designed and manufactured.

In recent years, the impacts of biotechnology and information and communication technology on the pharmaceutical sector have been profound. These impacts have been documented and analysed in many reports, including the recent ICSTI statement on *Embedding the PharmaChem Industry in Ireland* [5] and are therefore not addressed in this report.

There is growing evidence that the impact of nanotechnology on the pharmaceutical sector will be equally profound.

6.4.3 Intersection with Nanotechnology Roadmap

Nanotools and nanomaterials are already in use as enabling technologies for genomics and proteomics. The two most important impacts of nanotechnology in respect of the pharmaceutical sector will be in drug discovery and drug delivery.

Nanotools will allow imaging and manipulation of cellular and sub-cellular components, which will help to identify the function of these structures. This will in turn facilitate identification of target sites for new drugs and the mode of action of these drugs.

The impact of nanomaterials on drug discovery is already apparent, as many of the high-throughput technologies already in use for identifying molecules that bind to target sites are enabled by the use of nanostructured materials.

In drug delivery, nanomaterials will allow targeting of drugs to the most therapeutically beneficial site within the patients body. This, in turn, will reduce the size of the dose that must be

[5] *Embedding the PharmaChem Industry in Ireland, ICSTI Statement, (2003).*

administered and minimise unwanted side effects associated with use of the drug. The impact of nanotools on drug delivery will be in characterising the nanomaterials used to deliver the drugs under laboratory conditions and ultimately in production.

6.4.4 Opportunity for Ireland

Traditionally the competence of the pharmaceutical sector in Ireland has been in process scale-up and manufacturing. If the sector is to continue to prosper, it will need to develop competences in higher value activities.

The recent ICSTI report identified opportunities for the established sector in the synthesis of new drugs for pre-clinical and clinical trials and in the development of new manufacturing processes.

It is clear that the structure of these drug compounds on the nanometer-scale, and how this structure affects their subsequent processability and bioavailability, will be increasingly important. Nanomaterials will also be used as drug delivery vehicles.

Accordingly, there is an opportunity for the pharmaceutical sector to develop expertise in the use of nanotools and the manufacture of nanomaterials in order to secure a competitive advantage.

As evidenced by the increase in the number of collaborations within the pharmaceutical industry there is also an opportunity for small companies to use nanotechnology to develop innovative healthcare technologies, which could attract such partnerships.

6.5 Healthcare Sector – Medical Devices

6.5.1 Sector Overview

The medical devices sector includes medical implants and diagnostic, surgical and therapeutic tools. As is the pharmaceutical sector, the medical device sector is evolving rapidly to meet the new challenges presented by a dynamic market. The requirements of the regulatory authorities are also increasing the time and costs associated with bringing new products to the market.

The growth of the medical devices sector is now closely linked to that of the pharmaceutical sector because of increased interdependence for the development of novel therapies.

This is evidenced by an increased number of collaborations and alliances between medical device companies and pharmaceutical companies, which exploit new technologies for the development of new healthcare products.

6.5.2 Sector Roadmap

From a technological perspective the medical device sector is driven by the requirement to meet both the diagnostic and therapeutic needs of the medical professional and increasingly the needs of the patient managing their own health.

In recent years, as for the pharmaceutical sector, the impacts of biotechnology and information and communication technology on the medical device sector have been profound. These impacts have previously been documented[6] and are not considered in detail in this report.

Nanotools and nanomaterials are already being used to develop 'smart' materials and implants for medical devices and there is growing evidence that nanotechnology will have a huge impact on the medical devices sector.

6.5.3 Intersection with Nanotechnology Roadmap

Currently, the use of nanotechnology in the medical devices sector is largely confined to the research and development stage. However, it is expected these activities will lead to a large number of new nanotechnology enabled medical devices.

In diagnostics, nanotools and nanomaterials will allow the design of new sensors. Although the design and testing of nanoscale sensors will be expensive, once designed, the manufacturing costs should be low. The low cost and small size of the diagnostic sensors should facilitate collection of larger amounts of diagnostic data.

[6] *Converging Technologies: Pharmaceutical, Biotechnology, and Medical Device Industries, IDA Ireland, (2002).*

The use of nanomaterials in medical implants will enable the production of fully internal, biocompatible implants. Research in nanomaterials for tissue engineering is being used to develop biocompatible materials that can be used to restore, maintain or improve the function of human tissues and organs.

6.5.4 Opportunity for Ireland

Providing skilled graduates with expertise in the use of nanotools and nanomaterials will help to embed the existing medical device companies in Ireland and will also help to attract further investment in this sector.

There is an opportunity for the existing medical devices sector in Ireland to develop expertise in the use of nanotechnology, which would secure a competitive advantage in the emerging market of nanoenabled medical devices.

There is also an opportunity for medical device companies to establish collaborations and partnerships with the pharmaceutical industry both nationally and internationally, for the development of innovative nanoenabled products.

6.6 Agri-food Sector

6.6.1 Sector Overview

Within the agri-food sector the agriculture sub-sector is increasingly comprised of commodities businesses, with the producers adding relatively less value. In fact this sub-sector is characterised by falling prices and questions concerning it’s sustainability.

The food sub-sector is increasingly comprised of specialist businesses, with producers adding relatively more value. This is leading to tensions between the agriculture and food sub-sectors. Outlined in Table 6.4 are some of the challenges faced by this sector.

Table 6.4: *Challenges facing the Agri-Food Sector.*

Agri-Food Challenges
■ New crop-based products and new uses for more plant species.
■ New animal-based products and new uses for more animal species.
■ Lessening the risk of local and global climate change on food production.
■ Improve the quantity and quality of information and knowledge needed to ensure good stewardship of the environment and the available natural resources.
■ Improve the economic return to agricultural producers.
■ Enhance quality of life of agricultural families and communities.
■ Improve food health.
■ Increase food safety with security and assurance guaranteed.
■ Improve the functionality of food in terms of improving its contribution to nutrition and health.
■ The implementation of a secure and robust food tracability system.

6.6.2 Agri-food Sector Roadmap

The Agri-food sector has seen significant change in the past decades. In general, the sector has specific requirements and it faces specific challenges based on those requirements.

Currently, the most important requirements for the Agri-food sector are to increase the functionality of food and to ensure its complete safety.

In respect of the former, increasing functionality will include meeting the specific nutritional requirements of an individual on a specific occasion and providing a 'delightful' eating experience.

In respect of the latter, complete safety will include fork-to-farm traceability of all ingredients, preservation of the food product in its optimum condition and security against any form of tampering.

In the future the most important requirements will be the trend toward "personalised nutrition" and, in the long term, towards "personalised agriculture". The food products that will meet this medium-term need will be prepared for a specific individual (based on a knowledge of their genetic profile and complete medical history) and for consumption on a specific occasion (at home, at work, at night, in Winter, etc.). The above food products will not only meet the nutritional needs of the individual, but will also 'delight' the consumer.

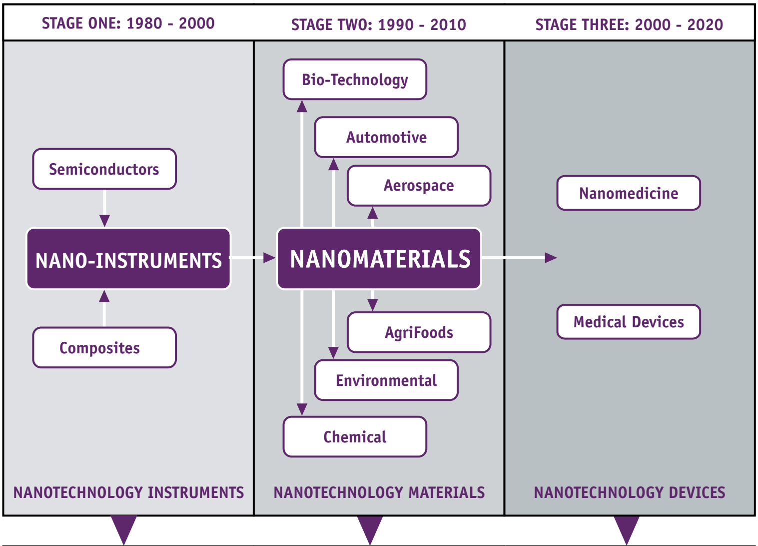
It should be recognised that all important trends in this sector will be shaped by the relevant legislative environment.

6.6.3 Intersection with Nanotechnology Roadmap

The impact of nanotechnology on the agriculture and food sub-sectors will be significant but different. It is thought that the food sub-sector will be an early adopter of nanotechnology, while the agriculture sub-sector will not.

Upon overlapping the above roadmap on the roadmap for the agri-food sector the following relationships can be determined, see Figure 6.2

Nanotools: The emergence of a mature sub-sector, capable of supplying an increasingly wide range of cost-effective nanotools, has already impacted significantly on research in the agri-food sector. The focus is currently on relating the structure of the food product on a nanometer scale to its function and its safety. Using nanotools, it will be possible to understand why a food has the attributes it has. In the future monitoring devices based on these tools and the insights gained from them will be placed on the production lines as part of quality control. Still further in the future it is hoped that it will be possible to determine the structure of a food, and the associated properties implied, at the nanometer scale.



FOOD RESEARCH		
Understanding food component influnce at the nano level	Ability to manage the interaction between food and people on nanoscale	Changes in people's eating habits mean that people will graze continuously
Understanding what is happening, what interactions etc.	Ability to design food functionality with huge value	Food will be made for customised purposes
Understanding the relevant interface factors that are important to food safety and functionality	Creation of intelligent surfaces for packaging and smart/ functional material that enables food safety	Food will start to converge food content toward medical diagnostic devices to ensure that value to be obtained from food is realised
Ability to optimise food functionality	Gaining control over ingredients and structures for future food functionality	

Figure 6.2: *Intersection of the nanotechnology roadmap with the Agri-Food sector roadmap*

Nanomaterials: As this sub-sector matures it is expected that a number of the additives, plant machinery and packaging suppliers will begin to supply products that have been improved by nanotechnology.

- In the case of additives, the drive will be to nanostructure these materials in order to increase their efficiency (solubility, bioavailability, etc.) so that the amount added can be reduced.
- In the case of the plant machinery, the drive will be to incorporate new nanomaterials or to nanostructure the surfaces of existing materials to minimise the adhesion of bacteria.
- In the case of packaging, the drive will be to reduce permeability, to reduce adhesion and, in general, to increase function, safety and quality.

Nanoenabled Products and Processes: The emergence of entirely new food products enabled only by nanotechnology is foreseen. As stated, the key trend in the sector is towards personalised food and it is already clear that nanotechnology will significantly enable this trend. Also foreseen was that nanotechnology-enabled advances in medical devices will be important. The ability to profile an individual, genetically and diagnostically enables the individualisation of food products.

6.6.4 Opportunities for Ireland

The opportunities for Ireland lie in two distinct areas:

Firstly, if Irish companies can develop a critical mass of understanding, competency and capability in:

- the relationship between the structure of a food product on the nanometer scale and its functionality and safety;
- the nanostructuring of ingredients and additives to reduce the amounts required; and
- the nanostructuring of packaging materials (to develop intelligent packaging and surfaces that are designed for hygiene and manage the quality of food).

it is possible that there will be opportunities for food businesses to achieve a substantial competitive advantage in the marketplace through innovation. This is likely to occur through securing the intellectual property rights to such innovations and, as a result, to own more of the value chain.

Secondly, the Irish food industry faces a significant logistics disadvantage (in cost and time) in being 3 days removed from major markets in Europe. The net result is that it is impossible to guarantee permanent stocking. Any innovation that would allow Irish produce to leverage developments in food preservations/additives, intelligent packaging and hygiene would help it to reach more markets with greater product consistency.

6.7 Polymers and Plastic Sector

6.7.1 Sector Overview.

The plastic and polymer sector is comprised of the following players:

- plastics manufacturers: monomer and polymer manufacturers;
- plastic converters/plastic moulders; and
- plastics manufacturing machinery.

Plastic converters/moulders dominate the Irish landscape and are best defined by the individual markets they serve, i.e. packaging, automotive, construction, electronics, etc.

The main materials used by Irish industry reflect global consumption, as suggested by the following list; PE, (33.5%), PP (19.5%), PVC (17%), others (9%), EPS (8.5%), PET (5%), blends (4%) and ABS/SAN/ASA (3.5%).

The choice of material is typically defined by the end-use, which will usually have specific technical or performance requirements, such as mechanical, chemical, thermal or optical requirements.

By their nature products tend to be high volume and have low unit values, so high levels of expenditure on automation is normal in the industry. This results in high barriers for new entrants and high levels of competition within the industry.

The markets served by this industry tend to operate on advanced agreed prices. However, virgin polymer prices are linked to oil prices and instability in oil markets can result in low margins.

To date innovation in this industry has tended to focus on process rather than products, as many manufacturers are serving OEMs[7] and thus manufacture to a specific design. There is, however, a shift away from this position as OEMs are demanding design input from their manufacturing partners.

The industry is increasingly under pressure to produce more environmentally sustainable products, and in areas such as the automotive industry must demonstrate end-of-life recyclability. This influences the choice of material and is likely to impact on the future evolution of this market.

Exports from Ireland in 2002 for plastics in their primary form were worth €169.4 million, and plastics in non-primary forms was worth €199.4 million.

6.7.2 Technology Roadmap

In an effort to move up the value chain companies are now working in partnership with OEMs to develop new products. The OEMs are seeking products, which demonstrate the following improved attributes:

- Improved/increased recyclability;
- Improved mechanical/optical and chemical performance to access new markets;
- Increased functionality, e.g. the inclusion of sensors, electronics and communications devices.

For indigenous companies to participate successfully in such partnerships, will require significant investment in research and development capability and necessitate increased interaction with the third level sector to access both facilities and skilled professionals. The focus for innovation for indigenous companies will be the key manufacturing processes in this highly cost competitive industry.

[7] *Original Equipment Manufacturer*

6.7.3 Intersection with Nanotechnology Roadmap

Nanotools: The development of nanotools has facilitated the development of a fundamental understanding of polymers at a molecular level.

Nanomaterials: The subsequent development of nanomaterials, and their incorporation into polymers, to give polymer nanocomposites offers the plastics industry a platform to launch a new generation of products. Specifically, polymer nanocomposites have been shown to exhibit significant performance improvements compared to both ordinary and reinforced polymers.

Nanoenabled Products and Processes: Table 6.5 gives some examples of the types of improvements shown to be possible, which are relevant to Irish industry. This is only a "flavour" of the possibilities offered to the plastics industry, but the greatest advantage is that polymer nanocomposites can be incorporated within current manufacturing protocols, without significant capital investment.

***Table 6.5:** Examples of the improvements possible with nanoenabled products and processes.*

Plastic reinforced structures	Improved impact resistance
Improved thermal properties	"Smart" packaging
Increased weatherability	Improved lubricity
Increased flame retardancy	Improved biocompatibility
Increased strength-to-mass ratio	Anti-bacterial action of implants
Increased thermal operating range	Increased stain resistance
Improved barrier properties	Reduced wear

6.7.4 Opportunities for Ireland

The main materials manufacturers will only develop a polymer nanocomposite that can sell into mass tonnage markets. Irish companies typically sell into, globally small, but nonetheless significant markets, and thus can develop specific polymer nanocomposite solutions to meet the demand of their specific market. Such developments are currently underway and offer near market potential.

Polymer nanocomposites can be viewed as the first wave of nanoenabled products. The next stage of development will be to increase functionality of products. This will involve the incorporation of sensors and communications devices to respond to external stimuli.

The Irish plastics industry will need to continue to be well supported by researchers in third level institutions, providing both technical support for specific projects but also ensuring that companies have access to well qualified graduates.

6.8 Construction Sector

6.8.1 Sectoral Overview

The construction industry needs little introduction. In Ireland the industry is composed of a range of players, from world leaders (e.g. CRH and Kingspan) to a large number of smaller but successful companies.

The industry produces a wide range of products covering almost every aspect of the industry; including aggregates, cement, insulation, timber, concrete products, piping and specialty products.

Given the bulk nature of the products, construction is not generally an export oriented business although many companies, through product innovation and differentiation are accessing international markets.

Globally markets tend to be served by local players, but companies such as CRH etc. now have global reach through acquisition of local production/marketing facilities.

The trends within the construction sector are to develop high performance materials through the incorporation of newer materials into established products, thereby creating more durable, efficient, cost-effective and superior buildings.

It must be recognised that practitioners in this industry are conservative and that any development must take account of this. The slow acceptance of timber framed housing in Ireland is an example of this, despite its acceptance in other geographies for decades.

6.8.2 Technology Roadmap

The key drivers for this sector are to meet the growing legislative and societal needs and still make a reasonable profit. This has created the need to combine activities such as the reduction of costs for building, with the improvement in durability, maintenance and health and safety. Traditionally, these would have been considered to be separate activities.

Due to the maturity of the industry, it is being compelled by legislation and public opinion to move actively towards the key goals of (1) cost reduction in the provision of new housing, (2) reduced environmental impact, (3) reduced energy consumption in manufacture and lifetime, (4) improved durability, (5) reduced maintenance costs and (6) significant weight reduction.

The key elements of this roadmap are as follows:

- to accelerate acceptance of innovative building technologies;
- to create an environment that allows for a construction systems solution;
- to industrialise the building process;
- to improve the construction of buildings; and
- to move more building to the factory.

6.8.3 Intersection with Nanotechnology Roadmap

Overlap with fundamental material science has led to nanotechnology being increasingly applied in construction materials research and development, in particular, nanotechnology relating to plastics and polymers.

Cement is the most widely used construction material. The synthesis and use of reactive and non-reactive nanoparticles and their role in cement binders, controlled releases of admixtures and new approaches to concrete reinforcement are crucial. It is expected that the addition of nanoparticles to concrete will improve the control of concrete microstructure beyond what is possible today with existing technologies. Therefore the product should be more durable in terms of its resistance and lifespan. The programming of time-release chemical admixtures in concrete will provide maximum effectiveness at the construction site and cement binders reinforced with nanofibres will impede crack formation and growth. It is important however, not to limit a discussion to cement/concrete and recognise the importance of plastics, glass and metals in the industry

More importantly, nanotechnology is now perceived as of high relevance to the construction sector overall, with a substantial investment into related research and development becoming available. This is expected to translate into a massive medium to long-term technical and economical impact on construction practice such as:

- increased strength-to-mass ratio of materials;
- improved insulation properties;
- improved weatherability;
- incorporation of passive solar energy conversion devices into building skins;
- smart windows;
- incorporation of sensors into key points of large structures;
- LED based lighting systems;
- improved water purification and treatment facilities;
- impact resistant structures;
- wear resistant road surfaces; and
- improved RF shielding in building envelopes.

6.8.4 Opportunities for Ireland

The opportunities for Ireland are in the development of innovative, proprietary products and processes that meet existing and future market demands. Given increasing demands for reduced energy consumption by occupiers it is likely that initial efforts will be in improved insulation materials without loss of fire retardancy properties.

The industrialisation of building presents a unique opportunity to Ireland, given its small size – buildings will essentially be prefabricated in factories and shipped to sites for assembly. The use of nanoparticles and fibres will allow control of setting/curing times for cement-based materials. The challenge here is to allow customisation of finish

The use of nanomaterials in plastic construction products may enable a significant reduction in material consumption without loss of mechanical strength. The development of such products will allow Irish companies to access international markets, in what is a cost conscious industry.

6.9 Conclusions

The identification of the points of intersection between the nanotechnology roadmap in Chapter Four and the accepted sector key roadmaps in this Chapter, makes it possible to identify specific nanotechnology opportunities for the key sectors comprising the Irish economy.

7.0 CAPABILITY

7.1 Background

The Task Force has evaluated the national nanotechnology capability. In doing so it has largely relied on a report prepared for the Board of Enterprise Ireland by its Industrial Products Division **(Appendix V)**, and on a report prepared for the Task Force by the Higher Education Authority **(Appendix VI)**. The existing national nanotechnology capability was evaluated under the following four headings:

- Third level Institutions;
- New Indigenous Companies;
- Established Indigenous Companies;
- Multinational Companies.

7.2 Third Level Institutions

The objectives were to determine the level and nature of research activity in nanotechnology, to take stock of the infrastructure available to researchers, and to identify the level and sources of funding available to support research and infrastructure.

The level of nanotechnology research activity in Ireland is, by international standards high. Enterprise Ireland estimates that there are 117 full-time professional researchers working in 10 internationally recognised nanotechnology research groups based in third level institutions. The Higher Education Authority estimates, based on responses received from third level institutions, that there are 114 researchers working in nanotechnology or nanotechnology related research across all third level institutions. The essential agreement is comforting. It should be noted that the above analysis excludes postgraduate students in these groups. The number of such students is estimated at 250, assuming a ratio of full-time professional researchers to postgraduate students of 1:2.

The nature of nanotechnology research in Ireland is diverse and forward looking but, in the absence of a detailed description of all current research projects, it is difficult to undertake a complete analysis. It is possible, taking the nanotechnology roadmap in Chapter Four, together with those research projects for which a detailed description is available, to undertake an initial analysis. This analysis is based on identifying what fraction of the national research effort is devoted to nanotools, nanomaterials, nanodevices and nanosystems and the development of nanotechnology enabled products and processes.

On this basis, our initial analysis reveals that the vast majority of current nanotechnology research activity is focused on the development and application of novel nanotools and nanomaterials, with growing interest in nanodevices and nanosystems.

The infrastructure available to researchers in general and nanotechnology researchers in particular has clearly improved as a result of a significant investment in recent years by the HEA. To date the HEA has invested €16.42 million in establishing the National Nanofabrication Facility at the NMRC based at University College Cork, and €14.65 million in establishing the Institute for Advanced Materials based at Trinity College Dublin. The HEA has also committed, again through the PRTLI, a further €9.07 million in programs within third level institutions that have a significant nanotechnology component.

Two issues, which have arisen in the course of consultation, are the following; first, the need for management to ensure open-access for academic and industrial researchers to these national facilities; and secondly, the need for specific funding mechanisms to support open-access.

The vast majority of the funding available to support research within third level institutions in nanotechnology is derived from the following sources:

- Higher Education Authority; through the Irish Research Council for Science, Engineering and Technology;
- Science Foundation Ireland;
- Enterprise Ireland;
- European Union.

The Irish Research Council for Science, Engineering and Technology has funded twenty-two nanotechnology or related projects and has allocated €1.97 million. Science Foundation Ireland has funded 15 nanotechnology or related projects and has allocated €45.86 million. Enterprise Ireland has funded forty nanotechnology or related projects and has allocated €6.47 million. The European Union is currently funding sixteen nanotechnology or related projects and has allocated €7.21 million.

Another issue, which has arisen in the course of consultation, is the lack of a mechanism by which the nanotechnology funding strategies of the above agencies can be co-ordinated.

7.3 New Indigenous Companies

It is known that there are a number of individuals, generally based in or associated with the leading nanotechnology groups referred to above, currently seeking funding to establish a nanotechnology start-up. It is a stated objective of Enterprise Ireland, and its growing number of associated investment funds, to support commercially viable high-potential technology start-ups. It could reasonably be expected that one new indigenous company will be spun-out of each of these groups between now and 2010.

Already two indigenous nanotechnology companies, namely Deerac Fluidics™ and NTERA, have been spun-out of these groups.

Deerac Fluidics™, established in 2000 by Prof. Igor Shvets, is a spinout from the Department of Physics in Trinity College Dublin. This nanotool company is developing a nanofluidic dispenser for use in high throughput drug screening. To date this company has raised €2 million in funding and currently employs 15 people based in Dublin.

NTERA, established in 1997 by Prof. Donald Fitzmurice, is a spin-out from the Department of Chemistry in University College Dublin. This nanomaterials company is developing paper-quality display technologies. To date it has raised €20 million in funding and currently employs 30 people based in Dublin.

Consistent with our analysis of the nanotechnology opportunity, these companies were initially focused on developing proprietary nanotools and nanomaterials that enabled innovative products or processes in major markets. As a consequence, these companies expect to gain a large share of new or expanded markets. Furthermore, they will rely on their established ownership of intellectual property to maintain their market share. Significantly, as these companies have become more product-focused, they have tended to describe themselves not as nanotechnology companies but as product or market focused companies.

7.4 Established Indigenous Companies

There are at least six established indigenous companies exploiting the opportunity offered by nanotechnology. For example, one company is seeking to increase the strength-to-mass ratio of its polymers. This company is proposing to meet this objective by incorporating nanometer-sized particles in the polymer mix. If successful, and having secured the related intellectual property rights, the company expects to move from being a commodity producer, to one of only a handful of companies in the world that can produce products using these improved materials.

Enterprise Ireland is seeking to encourage some forty of its client companies, mainly from the electronics, medical devices, polymer and plastics and construction sectors, to use nanotechnology to improve their products.

Specifically, Enterprise Ireland is seeking to support an increased number of applied research projects in third level institutions in nanotechnology that will benefit its clients. It is also seeking to encourage the establishment of a number of national centres that will work closely with its client companies on specific projects, while ensuring a supply of individuals skilled in nanotechnology. Enterprise Ireland has also recognised that it has a role in promoting Ireland as a premium nanotechnology location at home and abroad.

It is clear that Enterprise Ireland has invested significant time and effort in understanding how it can best assist established indigenous companies exploit the nanotechnology opportunity.

7.5 Multinational Companies

At the present time there are four multinational companies that have announced they are exploiting the nanotechnology opportunity in Ireland.

Intel has headquarters in Santa Clara, California and Irish operations in Lexlip Co. Kildare. Best known for its Pentium and Celeron microprocessors, Intel also makes flash memory and embedded semiconductor devices for the communications and industrial equipment markets. Intel's Irish operations are currently being expanded with the building of Fab 24, to incorporate Intel's 90-nanometre process technology on 300 mm wafers, the most advanced semiconductor manufacturing process in the industry. Fab 24 will be the fourth out of a total of five currently planned 300 mm fabs to be built or converted, and is the only Intel facility currently planned to execute 90-nanometre-process technology outside the US. Nanotechnology will enable Intel to continue to extend Moore's Law beyond 90-nanometer technology.

As stated, Fab 24 will house Intel's latest process technology, the most advanced semiconductor manufacturing process in the industry. The facility is scheduled for completion and full-scale production in the first half of 2004. This new 90 nm process combines higher-performance, lower-power transistors, strained silicon, high-speed copper interconnects and a new low κ dielectric material. This is the first time all of these technologies will be integrated into a single manufacturing process.

Intel's 90 nm process will feature transistors measuring only 50 nm in length (gate length), which will be the smallest, highest performing CMOS transistors in production. By comparison, the most advanced transistors in production today, found in Intel® Pentium® 4 processors, measure 60 nm. Small, fast transistors are the building blocks for very fast processors. These transistors feature gate oxides that are only five atomic layers thick (1.2 nm). A thin gate oxide increases transistor speed.

LittleFuse Ireland is based in Dundalk, a subsidiary of LittleFuse Corporation in Chicago, and is a world leader in the design, research and development and production of Transient Suppression Devices. Metal Oxide Varistors were first introduced to the plant in the 1970's. By the mid 80's the business focused exclusively on Zinc Oxide Varistors where market demand was rapidly growing. LittleFuse Ireland's interest in nanoparticle based powders stems from the increased sinter activity of higher specific surface area powders.

This can potentially reduce the processing temperatures of varistors leading to the use of cheaper electrode materials and higher voltage devices arising from reduced grain sizes. The company recognises the potential opportunities nanotechnology may provide. In terms of timeframe, they will focus on applying nanotechnology to their existing products and processes to reduce costs and maintain competitive advantage.

Elan Corporation develops and markets pharmaceuticals and drug-delivery technology. Its pharmaceutical business focuses on neurology, pain management, dermatology, antibiotics, and autoimmune diseases. Its drug delivery business developed and patented the NanoCrystal system for formulating poorly soluble compounds as nanoparticles, thereby increasing their surface area and their solubility. There are currently two pharmaceutical products that have been commercialised incorporating NanoCrystal technology, with several additional product launches anticipated over the next two years. The NanoCrystal technology is protected by 85 issued US patents and 48 pending patents.

Elan has established manufacturing scale capability for pharmaceutical products formulated using their proprietary NanoCrystal technology at their Irish development and manufacturing site in Athlone. A drug in nano-form can be incorporated into common dosage forms, including tablets, capsules, inhalation devices, sterile forms for injection, with the potential for substantial improvements to clinical performance.

Aerogen Ireland Ltd is a subsidiary of Aerogen Inc based in California, a specialty pharmaceutical company developing inhaled drug products to advance the treatment of respiratory disorders and chronic diseases. The company is focused on efficient, convenient delivery of aerosolised drugs to the lungs, and through the lungs to the blood stream. Its Irish operations are based in Galway where the core business is in the manufacture of pulmonary drug delivery devices. Aerogen's range of current and future products includes specialised nebulisers and breath-activated inhalers for marketing by Aerogen, as well as novel inhalers for leading pharmaceutical and biotechnology companies. Aerogen have recently established a small three-person team, based in Galway, to formulate drugs as nanoparticles for aerosol delivery. The company has stated that the recent changes to Elan in this country have led to the availability of some highly skilled individuals.

There are a small number of additional multinational companies undertaking nanotechnology research in Ireland, but they do not wish this to be reported on here.

IDA Ireland recognises that a large number of the multinational companies, which comprise its client base, have themselves recognised that the emergence of nanotechnology presents them with an opportunity to develop new and improve existing products and processes.

In some cases these companies are already engaged in nanotechnology research in Ireland (Intel, LittleFuse, Elan, Aerogen and others). In some cases the new and improved products and processes manufactured in Ireland, have been enabled by nanotechnology research undertaken at a company's other sites (IBM and Hewlett-Packard). In all cases these companies recognise the knowledge and skills produced by the existing research infrastructure as critical to their success and an advantage associated with being located in Ireland.

At the present time the IDA is seeking to understand, while supporting current opportunities, how to best leverage Ireland's existing nanotechnology capability to attract and retain multinational companies in all sectors to Ireland.

7.6 Conclusions

The existing nanotechnology capability within the third level sector is significant in global terms and focused on nanotools and nanomaterials, with increasing interest in nanodevices and nanosystems. Issues, which need to be addressed, include open access to national facilities and the coordination of nanotechnology funding and research.

There are a number of nanotechnology start-ups, which have spun-out of third level institutions. It is expected that this number will increase. These institutions are well placed to support established indigenous and local multinational companies as they seek to exploit the nanotechnology opportunity.

There are at least six established indigenous companies currently using nanotechnology to improve an existing product or process. Enterprise Ireland, however, has developed a strategy and approved an associated operational plan to significantly increase this number. This strategy will focus on forty identified companies in the electronics, medical device, polymer and plastic and construction sectors.

There are at least four local multinational companies currently using nanotechnology to develop new products or processes. The IDA is seeking to understand, while supporting current opportunities, how to best leverage Ireland's existing nanotechnology capability to attract and retain multinational companies in all sectors to Ireland.

8.0 NANOTECHNOLOGY AND SOCIETY

8.1 Background

To this point we have focused on the opportunities represented by the emergence of nanotechnology as a key enabling technology. However, it must be recognised that in tandem with these opportunities there exist a number of challenges.

In this chapter we focus on the challenges, in particular, on the challenge of ensuring that the above opportunities are exploited in a responsible and transparent manner that benefits society at large.

8.2 Short Term Challenges

It is widely accepted that there are no significant short-term regulatory issues in respect of nanotools.

Current knowledge suggests that there are few significant short-term regulatory issues in respect of nanomaterials, nanodevices and nanosystems.

Furthermore, it is the opinion of the Task Force, that these regulatory issues can be addressed by the relevant government agencies[8], at a national and international level, working with scientists and engineers in research organisations and companies.

The above agencies will need to focus on two key issues. First, is the establishment of standards, particularly in the area of legal metrology and the accreditation of laboratories providing independent testing services. Second, is ensuring that existing health and safety regulations are sufficiently robust to provide for the protection of individuals involved directly or indirectly with the preparation, handling and disposal of nanomaterials or products incorporating these materials.

In respect of the first issue, as companies and individuals purchase a wider range of nanotools and nanomaterials, or products incorporating nanotools or nanomaterials, from a growing number of sources; it will be essential to ensure that the goods are as represented by the vendor and that the procedure by which this is established to be so is agreed upon.

8 *Examples of these agencies include the Health & Safety Authority, the Irish National Accreditation Board and the National Metrology Laboratory.*

In respect of the second issue, the fact that the properties of materials, devices and systems structured on the nanometer scale are size dependent and may differ significantly from those of the corresponding bulk material needs to be addressed. In short, a more sophisticated approach to implementation of existing regulations may be required. It is important to note, in stating that the properties of a nanomaterial may differ significantly from those of the corresponding bulk material, we are not stating that they will necessarily be more harmful. Indeed, they may be less harmful, but that this is the case which will need to be established.

8.3 Long Term Challenges

It is thought that there will be few if any significant long-term regulatory issues in respect of nanotools.

It is believed that there will be a number of significant long-term regulatory issues in respect of nanomaterials, nanodevices and nanosystems.

Furthermore, it is the opinion of the Task Force, that these regulatory issues will need to be addressed by the relevant government agencies, at a national and international level, working with scientists and engineers in research organisations and companies and with representatives of the wider community in various national and international forums.

These regulatory issues will include those at the interface of biotechnology and nanotechnology, and relate to the development of nanodevices and systems that can emulate or intervene in important biological pathways with potential ethical or environmental implications.

These issues will also include those at the interface between information and communication technology and nanotechnology relating to the development of nanodevices and nanosystems that enable ambient communication and computating with implications for privacy and security rights.

8.4 Nanomaterials and the Wider Community

The lessons of the past must be learnt. For the scientists and engineers in research institutions and companies to simply assert that nanotechnology is safe is not a viable strategy.

Scientists and engineers must engage with governmental and non-governmental representatives to agree what the issues concerning the wider community are, and agree how best to use existing or new regulatory frameworks to transparently address these concerns.

This engagement should take place at both the national and European levels and should be actively promoted by the National Nanotechnology Forum.

9.0 NATIONAL NANOTECHNOLOGY FORUM

9.1 Background

A consistent observation made by the stakeholders, particularly those from academia and industry, was the need for co-operation among the stakeholders to fully exploit the nanotechnology opportunity for Ireland, while at the same time delivering value to the wider public community. It is in this context that the establishment of a National Nanotechnology Forum is proposed.

9.2 Role

The National Nanotechnology Forum would bring together industry, academia and the state agencies to build on and renew the shared vision and agreed strategy for nanotechnology in Ireland contained in this report. The specific roles of the Forum would be the following:

- Review, and when necessary, revise the definition of nanotechnology contained in this report to reflect key technology developments.
- Review, and when necessary, revise the description of the nanotechnology opportunity contained in this report to reflect key market developments.
- Review and when necessary, revise the description of the sector specific nanotechnology opportunities contained in this report to reflect key technology and market developments.
- Update, and when necessary repeat, the survey of nanotechnology capability in academia and industry contained in this report.
- Consider and when appropriate advise on the establishment and review of the proposed research clusters. It is envisaged that the responsible stakeholders will operate the above clusters operating within existing structures.

- Consider and when appropriate advise on the development of the national nanotechnology research capability. It is envisaged that the responsible stakeholders will cooperate to develop the above infrastructure.
- Consider and when appropriate advise on both the short and long term regulation of nanotechnology nationally and internationally, and on the concerns, if any, of the wider community as they arise.
- Consider and when appropriate advise on the promotion of Ireland as a leading nanotechnology location at home and abroad. It is envisaged that the responsible stakeholders will undertake the above promotion operating within existing structures.

The role of the Forum would also be to consider and when appropriate advise on the following broader issues in the nanotechnology context, which were raised in the course of the consultation workshops **(Appendix VII)**:

- **European Framework Programs** (specifically the nanotechnology specific inputs to the envisaged Frameworks 7 and 8).
- **Intellectual Property** (the identification and development of nanotechnology specific supports at a national level).
- **Education** (the promotion of new educational approaches within third level institutes that will ensure the required supply of highly interdisciplinary graduates).
- **Public Awareness** (the promotion of nanotechnology in a manner that ensures its development as an important activity in Ireland has the support of the wider community).

It is proposed that Forfás and the Irish Nanotechnology Association will convene the first meeting of the Forum, following publication of this report.

9.3 Conclusions

The immediate establishment of a National Nanotechnology Forum would represent a timely and effective response to the views of the key stakeholders that full co-operation is needed to fully exploit the nanotechnology opportunity for Ireland and deliver value for money in terms of a return on investment to the public community.

10.0 STRATEGY AND RECOMMENDATIONS

10.1 Background

The stakeholders have agreed on a national definition of nanotechnology. They have also agreed on the significance of the emergence of nanotechnology as a key enabler.

The stakeholders have identified opportunities for Irish industry to enhance competitiveness. They have also identified some specific technological and market opportunities for companies within key sectors. A survey of the capabilities that exist within academia and industry has been undertaken. This has been coupled to a review of the current activities of stakeholders. Some short and long term regulatory issues have been considered.

On this basis a national nanotechnology strategy has been developed and has given rise to a series of recommendations supported by the key stakeholders.

The stakeholders have agreed to the establishment of a National Nanotechnology Forum to facilitate a co-ordinated approach to exploiting the nanotechnology opportunity for Ireland.

10.2 National Strategy

The strategy, at the highest level, is to exploit the general and sector specific nanotechnology opportunities that arise for new and existing indigenous and multinational companies by facilitating the co-operation of the key stakeholders to achieve the following:

- The growth of a number of potentially high value companies spun-out of the relatively large number of internationally recognised nanotechnology groups active nationally.
- A significant increase in the number of established companies that are using nanotechnology to improve the performance or reduce the cost of existing products and processes to enhance competitiveness.
- A significant increase in the number of multinational companies that are using nanotechnology to improve the performance or reduce the cost of new and existing products and processes; to enhance competitiveness; and to embed existing and attract new foreign direct investment.

- The co-ordination of the funding of fundamental and applied nanotechnology research in third level institutions with a view to ensuring the necessary supply of skilled professionals; and with a view to building on the Ireland's broad-based nanotechnology activity to enable key sectors to exploit specific nanotechnology opportunities.
- The promotion of informed consideration by the wider community of the opportunities and challenges presented by with a view to transparent regulation that attracts the support of all.
- The promotion of Ireland as a leading Nanotechnology location internationally.

The establishment of a National Nanotechnology Forum will facilitate co-operation between academia, industry and funding agencies and promote Ireland as an effective cluster.

10.3 Recommendations

In the context of the above strategy, we recommend that:

(i) New Indigenous Companies

Enterprise Ireland continue to support the establishment and growth of indigenous nanotechnology or nanotechnology enabled companies through the mechanisms available to support high-potential start-ups.

(ii) Established Indigenous Companies

The Board of Enterprise Ireland fully implement their recently approved and highly commendable strategy aimed at using nanotechnology to improve the performance and reduce the cost of products and processes marketed by established indigenous companies and, thereby, to improve their competitiveness.

(iii) Multinational Companies

IDA Ireland employs the information contained in this report to further inform existing and potential client companies of the opportunity to develop nanotechnology enabled activities in Ireland and to actively support these projects.

(iv) Research Infrastructure

The relevant agencies co-ordinate funding of the national infrastructure necessary for internationally competitive nanotechnology research and also fund access to this infrastructure.

The relevant agencies co-ordinate funding of internationally competitive nanotechnology research with a view to building on Ireland's position of relative strength internationally and with a view to ensuring maximum return on the national investment.

The relevant funding agencies, research institutions and industry work together to establish thematic clusters focused on meeting strategic nanotechnology needs of key sectors.

Initially, research clusters be established to focus on meeting the specific skills and nanotechnology needs of the ICT and Healthcare sectors. These areas are prioritised on the basis of the potential return on investment, specifically the impact on and growth of export earnings.

(v) The Wider Community

The relevant government agencies bring together the representatives of research institutions and companies and the representatives of other government agencies and non-governmental organisations to ensure that the opportunities and challenges presented by nanotechnology are transparently exploited in a responsible and regulated manner that gains support from the wider community.

(vi) Profile

All stakeholders work together to promote Ireland internationally as a centre of excellence in nanotechnology.

(vii) National Nanotechnology Forum

A National Nanotechnology Forum be established to facilitate ongoing co-operation between the stakeholders and to ensure coherence in the national approach to nanotechnology and the opportunity it represents

10.4 Conclusions

The above strategy and recommendations are the result of an analysis of the national and international landscape by the stakeholders. It is essential that these recommendations be implemented in full if Ireland is to derive the social and economic benefits presented by the nanotechnology opportunity.

APPENDIX I: NANOTECHNOLOGY REPORTS

Appendix I: Further reading

Nanotechnology Research Direction: IWGN Workshop Report – USNSF, (1999).

Nanostructured Science and Technology: A Worldwide Study – USNSF, (1999).

Hurdles on the way to Growth, Commercialising Novel Technologies: The case of Nanotechnology – Helsinki University of Technology, Institute of Strategy and International Business, (2000).

Technology Roadmap for Nanoelectronics – European Commission, (2000).

Nanotechnology: Commercial Opportunity – Evolution Capital, (2001).

Nanotechnology in Ireland – Institute of Nanotechnology, (2001).

Nanotechnology in Australian Industry: Workshop Report – Industry Science Resources, (2001).

Future Needs and Challenges for Materials and Nanotechnology Research – European Commission, (2002).

Opportunities for Industry in the Application of Nanotechnology – DTI, UK, Foresight Conference. Institute of Nanotechnology, Stirling, UK, (2000).

Survey of Networks in Nanotechnology – European Commission, (2003).

New Dimensions for Manufacturing: A UK strategy for Nanotechnology, DTI, OST, UK, (2002).

Nanotechnology Opportunity Report – CMP Cientifica, (2002)

Embedding the PharmaChem Industry in Ireland – ICSTI Statement, (2003).

Converging Technologies: Pharmaceutical, Biotechnology, and Medical Device Industries – IDA Ireland, (2002).

APPENDIX II

Appendix II:	Task Force Members Sectoral Roadmap Panel Members International Benchmarking Panel Members Consultative Workshop Participants PA Consulting Irish Nanotechnology Association

Task Force Members

Prof. Donald Fitzmaurice (*Chair)*	UCD, NTERA, ICSTI
Dr. Robert Flood *(Mr Kevin Kavanagh, Mr. Kevin Sherry)*	EI
Dr. Alastair Glass	SFI
Dr. Jenny Melia	Materials Ireland, Irish Nanotechnology Association
Ms. Ann Murphy	DIT, ICSTI
Dr. Diarmuid O' Brien	Deerac Fluidics™
Dr. Gareth Redmond *(Dr. Aidan Quinn)*	NMRC
Dr. Mike Hopkins	Scientific Systems Ltd., ICSTI
Ms. Deirdre Lyons *(Ms. Catriona O'Kennedy, Ms. Siobhan Hanley)*	IDA Ireland
Dr. Eucharia Meehan (Dr. Lisa Higgins)	HEA
Dr. Norma O' Donovan	HRB

Secretariat

Ms. Paula McKillen	Forfás

Sectoral Panel Members

Electronics

Dr. Gareth Redmond	Group Director, Nanotechnology Group, NMRC.

Dr. George Bourianoff	External Programs Group in the Strategic Research Group, Intel.

Photonics

Prof. Eoin O'Reilly	NMRC.
Dr. David Bishop	Lucent.

Agri-Food

Mr. Garett Dee	Director AMT Centre, UCC.
Dr. Tim Roche	UCC.
Dr. Heribert Watzke	Head of Food Science, Nestle Research Centre, Lausanne.

Environment

Prof. Liam Downey	UCD/Maynooth/Teagasc /Technology Foresight.
Prof. John Sodeau	Centre for Research into Atmospheric Chemistry (CRAC), UCC.

International Benchmarking Panel Members

Dr Ray Oliver	Senior Research Fellow, ICI.
Dr. Stan Williams	Senior HP Fellow Director, Quantum Science Research Hewlett-Packard Labs.
Dr. Ramon Compano	European Commission DG Information Society - Unit A2.
Dr. Mike Roco	National Science Foundation, US.

Consultative Workshop Participants

Wednesday, 5th March, Life Sciences

Dr. Eric Jones	Stryker Howmedica
Dr. Niall Behan	Aerogen
Dr. Robert Forrester	DCU
Dr. Paul Tomkins	AIT
Prof. Terry Smith	NUIG
Ms. Catriona O'Kennedy	IDA Ireland
Dr. Jenny Melia	TF Member
Prof. Donald Fitzmaurice	NTERA, UCD, TF Chair

Wednesday, 5th March 2003, Government, Policy & Funding

Ms. Rosemary Durcan	IBEC
Dr. Ena Prosser	BRI
Dr. Norma O'Donovan	HRB, TF Member
Dr. Annmarie Mullen	Teagasc
Dr. Eoin O'Sullivan	SFI
Dr. Donal Carroll	EI
Dr. Gwilym Williams	BRI
Dr. Jim Lawler	Materials Ireland
Dr. Therese Murphy	SEI
Mr. Denis Curran	IDA
Mr. Kevin Kavanagh	EI
Mr. Kevin Sherry	EI
Dr. Robert Flood	EI, TF Member
Dr. Eamon Cahill	Irish Productivity Centre
Prof. Donald Fitzmaurice	NTERA, UCD, TF Chair

Thursday, 6th March 2003, Electronics, Photonics & ICT

Dr. Bill Lane	Analogue Devices
Dr. Jenny Patterson	Intel
Dr. John Donegan	TCD
Prof. Peter Kennedy	UCC
Dr. Johannes Vos	DCU
Prof. Tom Glynn	NCLA, NUIG
Prof. Brian MacCraith	DCU
Dr. Jim Greer	NMRC
Prof. Eoin O'Reilly	UCC
Dr. Mike Hopkins	Scientific Systems, TF Member
Dr. Aidan Quinn	NMRC, TF Member
Prof. Donald Fitzmaurice	NTERA, UCD, TF Chair

PA Consulting

Mr. Colm Reilly
Mr. Peter Durant
Ms. Lorna Murphy

The Irish Nanotechnology Association

www.nanotechireland.com, is managed by
Enterprise Ireland to encourage the development of nanomaterials and processes by Irish Industry.

APPENDIX III: NANOTECHNOLOGY DEFINITIONS

United States – National Nanotechnology Definition

Research and technology development at the atomic, molecular or macromolecular levels, in the length scale of approximately 1 – 100 nanometer range, to provide a fundamental understanding of phenomena and materials at the nanoscale and to create and use structures, devices and systems that have novel properties and functions because of their small and/or intermediate size. The novel and differentiating properties and functions are developed at a critical length scale of matter typically under 100 nm. Nanotechnology research and development includes manipulation under control of the nanoscale structures and their integration into larger material components, systems and architectures. Within these larger scale assemblies, the control and construction of their structures and components remains at the nanometer scale. In some particular cases, the critical length scale for novel properties and phenomena may be under 1 nm (e.g., manipulation of atoms at ~ 0.1 nm) or be larger than 100 nm (e.g., nanoparticle reinforced polymers have the unique feature at ~ 200-300 nm as a function of the local bridges or bonds between the nano particles and the polymer).

National Science and Technology Council (February 2000).

Japan – National Nanotechnology Definition

Nanotechnology is an interdisciplinary science and technology that encompasses information technology, biotechnology and the environmental sciences, materials science, etc. It is for controlling and handling atoms and molecules in the order of nano (1/1,000,000,000) meter enabling discovery of new functions by taking advantage of material characteristics unique to the nanometer scale, so that it can technological innovation in various fields. Nanotechnology also provides new materials, devices and innovative systems to fields in information technology, biotechnology, materials sciences, etc.

Council for Science and Technology (March 2001).

Europe – Commission Nanotechnology Definition

Nanotechnology refers to nanometer-scale science and technology. One nanometer (nm) is one billionth of a metre, i.e. around 80,000 times smaller than the width of a human hair. It is also the study and manipulation of tiny objects at the dimension of molecules and atoms. Nanotechnology involves the control of materials at the nano-scale, achieving miniaturisation through atomic and molecular manufacturing techniques. The potential benefits of nanotechnology are both pervasive and revolutionary.

European Commission (May 2002).

APPENDIX IV: NANOTECHNOLOGY FUNDING

Current funding level is estimated in the order of €40 million per annum[9] . It was thought that an increase was not needed. What is important is that such funding is committed over the long term, is co-ordinated and made as effective as possible and to ensure a higher and measurable return on investment. As it currently stands the National Development Plan 2000 – 2006 has a provision of €2.49 billion for Research, Technology, Development and Innovation (RTDI). Of this total, €698 million is earmarked for R&D in the third level education sector and €711 for implementing the Technology Foresight recommendations in relation to research.

The expression *committed* refers to the fact that Nanotechnology research is a long term process, requiring patience and time before results can be accumulated. Therefore the process cannot be subjected to quarterly or annual reviews but rather the investment needs to be monitored over a longer period, in the region of 3 – 5 years. Naturally, such an investment can only be made when the commercial aspects of the investment are clear and obvious to all.

The expression *co-ordinated* relates to the need to create a centralised approach to the management of nanotechnology initiatives. Funding is available from many forms today (SFI (€12.5 million pa), PRTLI (€20.4 million pa), Framework 6 (€1.3 billion)). The funding from SFI has worked to attract researchers from abroad and increase the profile of public funding of research, albeit from a very low base.

In global terms the public funding budget for a country the size of Ireland will always be small. Hence, it is important that a co-ordinated focus be applied to funding to ensure its effectiveness and a set of measurements that outline the effect of such funding on the national dividend. To compete, Ireland must ensure that it has effective funding to match the relative endeavours of other investors.

9 *This estimate is extrapolated from the 2000–2002 investment in nanotechnology projects from the Enterprise Ireland "Nanotechnology Strategy Document 2003–2008"*

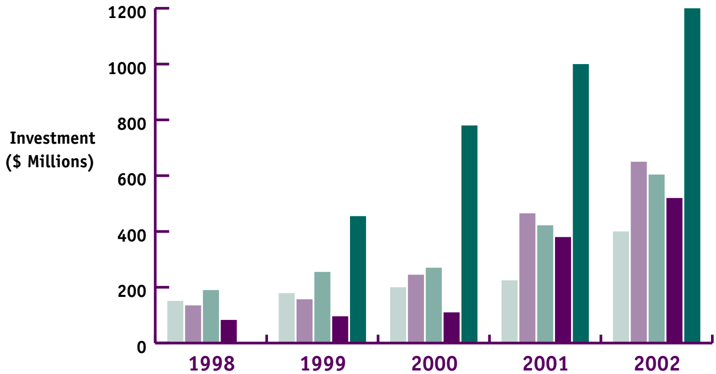
Another important aspect of funding relates to stages of development. There is a clear understanding within the Task Force that funding of Research and Development must ultimately relate to some definitive sense of product or solution, even if the lead-time of such a solution may be some years away. It would therefore be sensible to ensure that funding also extended to all the "tollgates" of the product development process. Hence, there is no point in spending all the funding at a research/development stage, the funding must extend over the entire lifetime of the solution.

It would be worthwhile to see an alignment and tighter co-ordination between the various funding bodies within the Irish public funding context to ensure that funding is managed as effectively as possible and that it is distributed over the entire integrated product development process.

Private Funding

With organisation Ireland can compete for "Smart Capital" from specialist Nanotechnology private funders. It is apparent that venture funding is entering the market, as demonstrated in Chart 1 below.

Chart 1: *Worldwide National Spending on Nanotechnology Research.*



	1998	1999	2000	2001	2002
Europe	151	179	200	225	400
Japan	135	157	245	465	650
United States	190	255	270	422	604
Others	83	96	110	380	520
US Venture Funding		455	780	1000	1200

Notes: (a) United States excludes non-federal spending (b) "Others" includes Australia, Canada, China, former USSR, Israel, Korea © All 2002 numbers are estimates. There are little quoted figures as yet. Source: Advisory Group on Nanotechnology Applications, NanoBusiness Alliance.

However such a funding environment must be managed and supported in order to attract and retain such degrees of funding as Ireland has no traditional angel culture and investment has traditionally always been at the later rather than earlier stages of investment.

Nanotechnology in itself is not an end. It can simply work to add different characteristics or capabilities to a product thus ensuring that the product produces some degree of market disruption in terms of price, quality, or characteristics. Hence nanotechnology value tends to be realised through licensing or trade sales. The business models supporting these types of exits are complex and it would be ideal for these issues to be addressed in advance.

Enterprise Ireland has already demonstrated a route to funding in the Seed and Venture Capital Programmes (1994–2000 and 2000–2006 (NDP)). Both these programmes showed that with incentives, the private investment market can be made to enter an arena (a €90 million investment from Enterprise Ireland leveraged some €350 million from private funding). Funding in Nanotechnology will be more complex, however there are solid reasons to suggest that a similar approach from Enterprise Ireland would be successful. It would be important that such an approach incorporated overseas venture capitalists with a branding in Nanotechnology to participate in such a venture. This would help deepen Irish venture capitalist capability in such investments and ensure the availability of follow-on funding and access to global markets.

APPENDIX V

NANOTECHNOLOGY STRATEGY DOCUMENT 2003 TO 2008, ENTERPRISE IRELAND

1. Introduction

This document sets out a medium term strategy for the development of nanotechnology capability in Ireland and how best to leverage the technology to the benefit of Irish industry. The Enterprise Ireland Mechanical Engineering (February 2001) and the Electronics Review and Strategies (December 2001) both identified nanotechnology as an enabling technology that will directly impact both these and other sectors over the coming years.

Clear targets and deliverables are set out in this document with appropriate phasing of investment and measurement of results to ensure impact and value for money. The main impacts of the strategy will be in the development and application of nanotechnology by existing clients (40 companies will be initially targeted to apply the technology to yield products which offer a significant competitive advantage), the creation of 8 new start-up companies and the development of research capability and centres of excellence employing 260 researchers covering the main area of commercial application of nanotechnology.

An intra agency team worked on the development of the strategy and preparation of this document, drawing on expertise in Industrial Products, HPSU, Materials Ireland and Science & Innovation. The team is: Robert Flood, Kevin Kavanagh, Jenny Melia, Nicola NicPhaidin, Kevin Donnelly, Joe Healy and Kevin Sherry.

The team consulted extensively in its preparation; with industry, client companies, multinational clients, IDA, Science Foundation Ireland, research institutes and universities, international experts and have also drawn on international reports.

Given the paramount importance of basic and applied research to the development of nanotechnology, it has been agreed with SFI that Enterprise Ireland (EI) will use this strategy as a basis for the rollout of a joint strategy and approach with SFI.

2. What is Nanotechnology?

Nanotechnology is like Lego on an atomic scale;

- It concerns the application of materials science and engineering to the design and control of matter on the atomic scale. The term nano derives from the nanometre (nm), which is one billionth of a metre. To put this scale in context a human hair is about 80,000 nm wide!
- Properties of a structure are dependent on the size of its constituent particles. It is now possible to manipulate these properties by controlling size and build structures that have specific properties designed in from the atomic scale. For example, carbon nanotubes as a structural material have a stiffness and tensile strength far superior to the strongest steels. Nanotubes have better thermal conduction properties than diamond and superior performance in conductivity to copper.
- Nanotechnology is a collective term for a set of technologies, techniques and processes rather than a discrete area of science or technology. It is multidisciplinary, drawing on chemistry, physics, biology, materials science and engineering.
- Nanotechnology is a pervasive, disruptive and truly enabling technology. It will displace some existing methods of production and facilitate the development of new products across most industry sectors. As a consequence it has enormous potential to provide many commercial opportunities in the short to medium term particularly in the Engineering, Electronics and Biotechnology/Healthcare sectors.

2.1 Nanotechnology – a new approach to fabrication

In manufacturing terms there are currently two approaches to fabricating products; (1) from the top down, by cutting, machining etc. until the desired shape is achieved, or (2) from the bottom up, by manipulating individual atoms/molecules to form larger functional assemblies (atomic Lego).

Traditional manufacturing takes materials with fixed properties and adapts them by processing to suit a required purpose. This leads to compromises and wastage of excess materials (like carving a house out of a solid rock).

Nature has built the most complex systems, such as the human body, by assembling the fundamental building blocks on the nanometre scale. Nanotechnology will allow this type of process to be copied and to build function into materials from the atomic level. Thereby, reducing waste. Structural applications will be stronger, lighter and more durable than those produced by traditional methods while electronic devices will be smaller, more powerful and consume less power.

2.2. An interdisciplinary technology

Both the top-down and bottom-up approaches of nanotechnology demonstrate the interdisciplinary nature of the technology. The top-down approach draws heavily from engineering and electronics (e.g. lithography) while the bottom-up approach draws more from chemistry and biology - addressing a nanotechnology problem requires inputs from a range of disciplines in a team.

Accordingly, a critical requirement for the development of nanotechnology in Ireland will be to supply graduates with expertise in a range of disciplines, using the traditional university model. Some organisations e.g. NMRC (Ireland) and Minatec (France) are developing graduate training programmes covering a wide range of skills.

2.3. A disruptive technology

Nanotechnology is a disruptive technology i.e. it will displace some of the existing methods of production and facilitate the development of new products. It has enormous potential and will affect most industry sectors. Technology platforms find applications in the optics, catalysis, biomedical, coatings, pharmaceuticals and structural industries.

For example the application of nanotechnology in the electronics industry will potentially displace current systems to yield smaller and more powerful devices. However it will require the industry to develop completely new architecture (fundamentally different designs) for such devices. Accordingly, most electronics corporations (e.g. Intel, IBM, Hewlett Packard and Fujitsu) are funding nanotechnology research in a significant way e.g. HP has established a Quantum Science research group employing 100 people.

Early adopters in established sectors (e.g. plastics, engineering and construction) can steal a lead on competitors by applying the technology to their current products/processes to produce products with superior performance characteristics or significantly reduced cost.

3. Global Market Analysis

Nanotechnology is a pervasive enabling technology with wide application across a range of sectors and markets. Set out below is an analysis of some potential application areas.

As will be seen from the analysis below the potential scope of greatest application for EI clients is among existing clients in the Precision Engineering, Electronics and Biotech/Healthcare area. It is envisaged that the number of existing EI client companies who can utilise this technology to significant benefit in the short-medium term may be about 40 companies. EI will immediately undertake an awareness programme with these companies. These are companies with the technical, management and financial resources to assess and develop the opportunity.

Given the embryonic stage of development of nanotechnology, a small number (8) of specific nanotechnology start-up companies are envisaged over the next 5 years.

3.1 Application Areas

Nanotechnology is about making existing materials/devices better *(called passive applications)* and making materials/devices never before possible *(called active applications)*. The distinction between these applications also indicates the likely rate of adoption of the technology by industry and also the industry segments that are likely to adopt them. Passive applications are already in the market (GM, Toyota, tennis balls) and offer the potential for established companies to develop or maintain their competitive advantage by applying the technology to their products or processes. Active applications have a longer time horizon and will be the source of new start-up companies and will form the basis for radical technological change in multinational corporations.

It is difficult to forecast the market value for nanotechnology applications. In the case of many active applications the market does not yet exist (e.g. non-CMOS electronics). In the case of passive applications it depends on the extent to which the technology will penetrate specific markets and/or which of the competing technologies will dominate. For example both nanoparticles and carbon nanotubes are both excellent drug delivery systems, but it as yet unclear, which will dominate the market.

To simplify the identification of the end markets and potential market size the following top-level application areas are discussed.

- Electronics
- Pharmaceuticals
- Medical devices and biotechnology products
- Chemicals & Materials
- Energy

3.1.1 Electronics

The electronics semiconductor market is currently dominated by silicon-based technologies. The market is demanding device miniaturisation with increased performance (i.e. increased processing speed, greater data storage capacity, reduced energy consumption). Nanotechnology is identified as a route to increased performance and significant size reduction. The European Commission estimates that the value for non-CMOS semiconductors will be between 5% and 7% of the total electronics chip market by 2004. This equates to a market valuation of €15 billion to €30 billion for electronics applications of nanotechnology by 2004.

One of the goals in electronics is to use individual atoms or molecules as electronic components, which will enable significant size reductions with increased performance. Moore's Law predicts the size reduction of integrated circuits with time. To continue its recent trend the industry must move rapidly into the nanosized domain using methods other than the current top-down approach.

3.1.2. Pharmaceuticals.

The pharmaceutical industry is driven by regulation and market demand for more effective, lower dose drugs with fewer side effects. Nanomaterials have the potential as drug delivery vehicles to both target specific organs and only dose the drug in response to specific triggers from the body.

The UK Department of Trade and Industry (UK-DTI) estimates that by 2015 50% of all pharmaceutical production will depend on nanotechnology. This equates to a market value of c €3.5 billion.

For example, many drug systems have been developed but never marketed due to their poor solubility in water. Elan has developed a proprietary milling system (NanoCrystal,) that reduces the size of the drug particles to the nano size domain. This allows the particles to be suspended in a liquid and the drug delivered orally.

3.1.3. Medical devices and biotechnology products

Miniaturisation, non-invasive procedures and multi-analyte sensing are key drivers in these sectors. Nanotechnology enabled products currently account for 1% (€100m) of the medical device market. This is expected to double every two years and includes devices, wound dressings, gene therapy and medical diagnostics.

For example, the National Centre for Sensor Research in DCU is developing an immuno-sensor that will enable several chemicals to be analysed simultaneously on a sensor the size of a pinhead.

3.1.4. Chemicals & Materials

Key drivers in this market are improved yields, higher purity and cost reduction. Materials produced by this sector include catalysts and ceramics. By 2015 the market for improved catalysts is forecast to treble to c €100 billion, while ceramics are forecast to treble to circa €70 billion. The UK-DTI estimates that nanotechnology will command 35% of these markets.

However, even the most novel materials will eventually become commodities. e.g. In 2000 carbon nanotubes cost between €300 and €1,500 per gram. They now sell for €20 to €100 per gram. This suggests that efforts should be focused on developing intellectual property around products or processes rather than the manufacture of materials, in the long term.

3.1.5. Energy

The focus of international energy research is to reduce global dependence on fossil fuels.

The United States National Science Foundation (US-NSF) estimates that using low power nanomaterials based LEDs for lighting could reduce energy consumption by €100 billion per annum by 2015. For example, solar cells based on nanostructured materials will operate in harsher environments and have higher conversion efficiencies than current systems. Together with improved batteries this will dramatically improve performance.

3.2. Market development timescales

Many nanotechnology-enabled products are already currently on the market e.g. sunscreens, tennis balls, abrasive media, and automotive steel. However, it is predicted that within the next five years the number will increase exponentially.

Improved products will be deployed in existing and new markets. New products will be deployed in new markets. Many organisations have made estimates of the potential global market. These are all estimating a very large passive market, in excess of €1,000 M by 2008 from its current very low level.

Below is outline of the estimated time to market for product applications where nanotechnology is forecasted to have a significant impact, (UK-DTI 2002).

Product applications	Time to market
Pigments, cosmetics, sunscreens, self-cleaning glass, drug delivery, lab-on-a chip, surface analysis tools, nanocomposites	Current commercial applications
Flat panel displays, advanced batteries, fuel additives, diagnostics, solar cells, hard disc data storage, drug discovery, stronger cutting tools, production of commercial quantities of carbon nanotubes	1 - 5 years
Targeted drug delivery, new generation lithography, advanced biocompatible composites	5 - 10 years
Fuel cells, quantum computing, bottom up fabrication, Nanoelectronics	11 – 20 years

3.3. Global Investment in Nanotechnology

Developed economies are spending increasingly significant sums on research. The NSF estimates that global funding for nanotechnology rose from €400m to €2,000m between 1997 and 2002. This is split evenly between government and private sector funding.

Venture capital funding of nanotechnology commenced in earnest in the mid 1990's. However since quarter three 2001 there has been a surge of interest, to some extent bucking the trend in other sectors. There were 95 venture capital funds with a strong focus on nanotechnology at the end of 2001 with 42 based in the USA. There are no such specific funds in Ireland. The UK is the dominant European player for venture capital funds focused on nanotechnology.

4. Profile of Ireland's Current Capability in Nanotechnology

4.1 Third Level Institutions

The quality and extent of nanotechnology research activity in Ireland is considered high by international standards. There are approximately 130 researchers working primarily in 10 research groups in universities and research centres. The leading centres are:

- NMRC (UCC) which was established with HEA funding and specialises in the application of nanotechnology to microprocessors and specific electronic components;
- TCD which has specialised in materials and pharmaceuticals applications and which was more recently approved substantial funding for basic research by SFI;
- DCU specialises in applications in sensors and biotechnology/healthcare.

There are two start-up nanotechnology companies. Deerac Fluidics™ (TCD) and NTERA (UCD) have spun-out of these research groups. Multinational corporations in Ireland fund a limited number of research projects in the universities e.g. Intel is funding work in UCC.

Funding for research in Ireland comes from four main sources; Enterprise Ireland, the Higher Education Authority (HEA), the European Commission (EC) and more recently Science Foundation Ireland (SFI). Only the European Commission has dedicated nanotechnology research funding.

Enterprise Irelands commitment to nanotechnology between 2000 and 2002 is;

- Advanced Technology Research Programme — €1.2 million,
- Basic Research (2002 only) — €130 k
- Innovation Partnerships — €133 k
- Research Innovation Fund — €1.3 million

HEA funding for nanotechnology was directed at providing infrastructure, particularly in the NMRC;

- National Nanofabrication Facility (NNF) — €12.7 million
- Nanophotonics centre within the NNF — €15.2 million

EU funding is mainly under the Framework and CRAFT programmes. The figures quoted below are the total project values of current projects and exclude completed projects;

- 16 projects — €13.6 million

The EU has set aside €1.3BN for nanotechnology under the 6th Framework Programme.

SFI has funded 5 projects with significant nanotechnology content. While SFI is directing funding at ICT and biotechnology, nanotechnology is a key enabler in some areas of both.

- 5 projects — €25 million

4.2 HPSU Activity and EI Client Companies

There are currently only two nanotechnology EI client companies Deerac Fluidics™ and NTERA.

Professor Donald Fitzmaurice (UCD Chemistry) established **NTera Ltd.** in 1997 to develop applications for nanostructured films. The company is developing display products based on nanostructured metal oxide films. Between 1997 and 2002 the company received €17.6 million in equity investments from Cross Atlantic Capital Partners and Evolution Capital. It currently employs 22 people. NTera's business model is to generate revenue from product sales and licensing opportunities.

Deerac Fluidics™, formerly Allegro Technologies was founded in 2000, as a spin off from Professor Igor Shvets research group in TCD physics department. The company developed a patented nanofluidic liquid handling system that can dose nanolitre volumes of liquid. There key target markets are the pharmaceutical and biotechnology sectors. Currently the company is located in the TCD Innovation Centre and employs 8 people.

Both companies are still in their infancy but have the following characteristics:

- The companies derive from universities and not industry;
- The promoters have been typically working on the technology for up to 10 years;
- The core employees originate from within the research group;
- The promoters have actively been involved in major EU funded projects.

It is likely that the new HPSU's targeted as part of EI's strategy will also emerge from the third level research community.

4.3 Established EI Clients

A number of client companies, in the medical devices, plastics and construction sectors are undertaking research in nanotechnology. While the companies are at varying stages of development (from initial feasibility studies to market launches) common characteristics of these companies are clear:

- The companies are leaders in their respective fields;
- The companies are well managed, profitable and committed to innovation and R&D;
- Nanotechnology is identified as a route to defending or establishing market position;
- Adoption of the technology is driven by market demand for price, improved performance and/or enhanced functionality.

4.4. Multinational Corporations in Ireland

The major multinational corporations in Ireland in all sectors are affected by developments in nanotechnology. Very many are already significantly involved through work at their parent company e.g. IBM, Intel and Bayer. In line with government strategy, as these companies move up the value added chain they will increasingly engage in nano-related areas. For example, Hewlett Packard Ireland received R&D Capability funding from the IDA to set up an R&D centre.

Moreover multinationals invest in nanotechnology in Ireland by sponsoring research projects in third level institutions. The Irish operation typically has a discretionary budget often supported through EI's Innovation Partnership scheme.

5. Areas of opportunity and growth potential for Ireland

The opportunities for Ireland in nanotechnology are wide ranging. It is not solely the preserve of high tech start up companies and academics

Based on our analysis of the existing capability in Ireland and an analysis of the potential market applications the following opportunities were identified;

Passive Applications

- Using materials for engineering/construction, plastics e.g. high heat plastics for automotive application
- Using materials and coatings for medical devices e.g. anti-bacterial coatings
- Display technologies
- Drug delivery systems
- Sensors

Active Applications

- Electronics
- Medical diagnostics
- Display technologies

The greatest scope for the development of nanotechnology capability in Ireland lies in the adoption and application of this technology by existing Irish companies in Precision Engineering, Electronics and Biotechnology/Healthcare sectors. Some 40 such companies have been identified by applying the technology to existing or new products could develop proprietary products that will significantly differentiate them from the competition.

The rate of adoption of the technology by these established companies will depend on the level of activity within the third level sector and its ability to transfer the technology to Irish based companies. A chart showing the areas of opportunity for the development of Nanotechnology in Ireland and the associated companies is appended.

The main source of start-ups, which is likely to be more limited in terms of overall impact (8), will be from universities.

6. Primary targets for the development of nanotechnology 2003-2008

Nanotechnology in Ireland is at a very early stage of development. Ireland can participate in the dramatic growth in this technology by focusing its limited resources in niche areas. To achieve focus the following high-level EI targets are proposed for the period 2003 to 2008:

- Encourage and support 8 new high potential start ups;
- Encourage 40 established EI clients to investigate, adopt and apply nanotechnology in their products or processes with the objective of 20 companies succeeding within 5 years;
- Encourage a doubling in the number researchers working in nanotechnology from 130 to 260 researchers over the period.

Objective1.
Eight new high potential start-ups between 2003 and 2008

The high levels of activity in universities and research centres indicate that this will be the primary source of new start-ups. A limited number of additional projects may come from ex-patriots but work in this area is only being planned.

Proposed Initiatives

The initiatives will focus on maximising the likelihood of spinning out Irish owned companies, rather than intellectual property sales or licensing to third parties. A team lead by the Engineering Department, with Industrial HPSU, Materials Ireland and the Irish Nanotechnology Association will:

- entrepreneurs with commercial projects at an embryonic stage, and assist them in the development of business plans and management development;
- Work with the Campus Company Programme resources to ensure Enterprise Ireland CORD and similar funding is targeted at these researchers;
- Pro-actively introduce research teams to sources of funding;
- Investigate the need to establish a joint Enterprise Ireland and private sector nanotechnology fund;

- Make Enterprise Irelands technical expertise available to the Irish venture capital community to assist in the evaluation of projects;
- Encourage ex-patriot entrepreneurs to return to Ireland in conjunction with EI's overseas offices and other networks.

Objective 2. Encourage some 40 established Enterprise Ireland client companies to investigating, adopt and apply nanotechnology in their products and processes.

Established companies may be slow to embrace nanotechnology on the misunderstanding that it is primarily applicable to high technology electronics companies. It is intended that 20+ of the 40 companies most likely to immediately benefit from nanotechnology will be applying the technology with substantial benefits within 5 years.

Proposed Initiatives

- Undertake a series of briefing seminars focused on specific sectors. These will be aimed at clients with the capability of adopting the technology and carried out in association with Materials Ireland and the Irish Nanotechnology Association.
- Assist these companies to establish their specific needs and to broker introductions with technology providers.
- Enterprise Ireland will work with these companies to identify the most suitable funding mechanisms to support the adoption of the technology, initially through Feasibility Studies but also through Commercialisation Fund, Innovation Partnership, Research, Technology & Innovation funding etc.
- Work with the Programmes in Advanced Technology to identify, prepare and target sectoral activities under the Commercialisation Fund.
- Encourage a limited number of clients to participate in nanotechnology consortia under the Framework Programme 6.
- Encourage co-operative research between HPSU's and established companies.

Objective 3. Increase the number of applied research projects in nanotechnology linked to and likely to benefit Enterprise Ireland clients.

Nanotechnology research by third level institutions is sporadic and covers a wide range of topics. Enterprise Ireland will use its position to direct funding towards specific activities that most likely can be exploited by Enterprise Ireland's clients.

Proposed Initiatives

- Enterprise Ireland funding schemes for third level institutions to consider including support for a business plan and management development. The scheme guidelines for third level funding would need to be modified to reflect this requirement.
- Enterprise Ireland will run a series of "technology watch" initiatives focused on the nanotechnology and more specifically the applications relevant to Irish industry.
- Encourage Irish research groups to increase their level of participation in Framework Programme 6 projects.

Objective 4. Encourage the development of the centres of excellence to exploit the main areas of potential from the application of nanotechnology.

Up until recently the National Nanofabrication Facility, based in the NMRC was the only established, dedicated nanotechnology centre. Its focus is on electronics applications.

Proposed Initiatives

- Work closely with SFI, the academic community and Enterprise Ireland clients to encourage the development and coordination of the centres of excellence to generate a critical mass in the applications with the most commercial potential.
- Enterprise Ireland will work with international centres of excellence to develop opportunities for Irish researchers to work with global leaders and access overseas facilities.
- Work closely with SFI, the academic community and industry to identify and attract key global experts to establish research groups in Ireland.

Objective 5. Increase the profile of Irish nanotechnology capability both at home and overseas.

Ireland, even at its current level of activity, is recognised as being a premier division player in nanotechnology. To promote the growth of research and foreign direct investment the following are recommended

Proposed Initiatives

- EI, with other parties to assist an international and domestic public relations campaign targeted at industry analysts, nanotechnology media (e.g. SmallTimes.com, MIT Technology Review) and international nanotechnology associations (e.g. The Institute of Nanotechnology).
- Encourage domestic nanotechnology events around prominent international speakers and content.
- Encourage the Irish Nanotechnology Association to participate at targeted international nanotechnology trade shows.
- Utilise the Irish Nanotechnology Associations web portal (www.nanotechireland.com) to brand nanotechnology in Ireland.

Objective 6. Develop specialist-training programmes at graduate level

Due to the multidisciplinary nature of the technology specialist training programmes at graduate level must be developed.

Proposed Initiatives

- In conjunction with key stakeholders in the research community and industry to identify the skills required to embrace nanotechnology.
- Identify current training programmes in nanotechnology overseas.
- Assist in the development of graduate level training programme.

Objective 7. Assist researchers develop a rigorous approach to IP protection.

Because nanotechnology is embryonic, fast moving and multidisciplinary it gives rise to a unique set of problems in the area of intellectual property protection.

Proposed Initiative

- In consultation with IP experts Enterprise Ireland will undertake, on a pilot basis, an assessment of the procedures currently being used by Irish researchers while undertaking Commercialisation Fund projects.

Technology Platform	Nanostructured Materials	Potential Adopters	Multinational Corporations	Research Projects
Nanostructured	NTERA,	Sifco, Nypro, Screentech, Mergon, Holfeld, McFarland, Barlo, Athlone Extrusions, Rotofab, JFC Tuam, Killarney Plastics, Vita Cortex, Freefoam, Basta, Kingspan, Qualceram Shires, Techcrete, Vitratiles, Quality Plastics, MFP, Roadstone	Intel, IBM, Xerox, LittelFuse, Ceram Optec, GE Superabrasives, Elan	UCD, DCU, UCC, TCD, NMRC, MI (TCD & UL)
Nanoparticles	NTERA	Vistamed, Trinity Biotech, Xenith, Protek, Tridelta, Megazyme, Clearstream, Vita Cortex, Freefoam, Vitra Tiles,	Boston Scientific, Abbott, Amersham, Bayer, Biotrin, GE Superabrasives, Elan	UCD, TCD, NMRC

Nanoporous Materials	NTERA	Catalytic Industries Oglesby & Butler, Megazyme	Elan,	UCC, MI (TCD & UL)
Fullerenes				
Carbon Nanotubes		Flexachem, Mergon,	Intel, IBM, Xerox, LittelFuse, Ceram Optec,	TCD, NMRC
Materials	Gem Plastics			
Nanofibres				MI (TCD)
Nanoelectronics		Betatherm, Mica & Micanite, Scientific Systems, Connaught Electronics, Eblana, Magnetic Solutions	IBM, Intel, Hewlett Packard, Agilent, Analog Devices, Cypress Semiconductor, Eurotherm,	NMRC, TCD, UCD, UCC
Nanowires			IBM, Intel, Hewlett Packard, Agilent, Analog Devices, Cypress Semiconductor, Eurotherm,	TCD, UCD, NMRC
NEMS			Hewlett Packard	NMRC
Nanofluidics	Deerac FluidicsTM		Hewlett Packard	TCD

Potential industrial adopters nanotechnology

Potential application areas for different types of nanomaterials are outlined below:

- **Nanostructured** materials will find applications as composite materials in structural, coatings, drug delivery, display systems, barrier materials and abrasives;
- **Nanoparticles** will find applications as drug delivery systems, catalysis, batteries, diagnostics and cosmetics;
- **Nanoporous** will find applications in filtration, purification, catalysis and electronics;
- **Fullerenes** are carbon-based materials that are biocompatible and potentially will be used for drug delivery;
- **Nanotubes** will find applications in displays, electronics, drug delivery and structural applications;
- **Nanofibres** will find applications primarily in structural and composite materials;
- **Nanoelectronics** is the utilisation of molecules or groups of molecules as components in electronic circuitry;
- **Nanowires** will be used as sensors or to connect nanoelectronic devices;
- **Quantum** dot will be used in diagnostics and electronic devices;
- **Nanoelectromechanical systems** (NEMS) will enable the further reduction of electromechanical devices;
- **Nanofluidic systems** will be used in drug delivery and dosing systems, primarily in the biomedical sector.

APPENDIX VI

SURVEY OF NATIONAL NANOTECHNOLOGY CAPABILITY

The National Nanotechnology Capability

The national nanotechnology capability has been surveyed under the following two headings:

- Human and Physical Infrastructure (Section 1); and
- National and International Funding (Section 2).

The relevant findings are tabulated below.

Section 1 – Human and Physical Infrastructure

1. Research Institutions

2003		
Institute	**Department - Centre**	**Full-Time Professional Researchers**
DCU	NCSR RINCE	13 4
DIT	FOCAS	5
Media Lab	Nanostructures	2
UCC	NMRC Dimensional Solids	18 5 1
CIT	Applied Physics	2
NUIG	Optics Chemistry	1 5
Athlone IT	PDC	4
TCD	Chemistry & Physics	35
UL	Materials Science Materials Institute	11 5
UCD	Chemistry	6
WIT	Materials	3
NUIM	Chemistry	1
Total		**117**

Section 2 – National and International Funding

1. Enterprise Ireland

A. Enterprise Ireland Nanotechnology Related Funding 2000 - 2002

2000-2002				
Programme	**Projects Supported**	**Funding Committed**	**Researchers employed**	**Institution/ Centre**
BASIC research	10	1.15M	14	TCD (Phys), TCD (Chem), DCU (Chem), DCU (Bio)
Applied with companies)	7	€0.17M	9	TCD (Phys), TCD (Chem), CIT, UCC (Chem)
Applied (RIF/ Strategic, Advanced Technology Research Programme)	16	€3.6M	43	TCD (Phys), TCD (Chem) TCD (Comp), UCC (NMRC), WIT, UCG (NCLA), UCG (Chem), UCC (Chem), DCU (NCPST), DCU (NCSR), DCU (Phys), UL (Mat)
TOTAL	**33**	**€4.92M**	**66**	

B. Enterprise Ireland Nanotechnology Funding 2003 (September)

i. Proof of Concept

Researcher & Institution	**Project**	**Funding**
Dr Mark Towler Materials & Surface Science Institute University of Limerick	Anti-bacterial bone cements	€352,850
Dr Carmel Breslin Department of Chemistry National University of Ireland, Maynooth	Metal dispersed catalysts: anodes in fuel-cell technology	€85,200
Prof. Werner Blau Department of Physics Trinity College, Dublin	Functionalised carbon nanotubes as polymer building blocks	€77,072
	TOTAL	**€215,122**

ii. Technology Development

Researcher & Institution	Project	Funding
Prof. Donald Fitzmaurice Department of Chemistry University College, Dublin	Commercialisation of a proprietary patterned nanoparticle technology	€296,000
Prof. Werner Blau Materials Ireland Polymer Research Centre Trinity College, Dublin	Improved product performance by functionalising inorganic nanoparticles – a quantum leap for industrial products	€341,400
Dr Khalil Arshak Department of Physics University of Limerick Limerick	Ingestible sensor string based on nanomaterials for real time measurement of intestinal activity in an ambulant physiological setting (MIAPS)	€366,218
Prof. Brian MacCraith National Centre for Sensor Research Dublin City University	Novel optical sensor system for personal healthcare monitoring	€333,520
TOTAL		**€1,337,138**

2. Irish Research Council for Science, Engineering and Technology

2000-2003			
Programme	Projects Supported	Funding Committed	Institution /Centre
Postgraduate* *(1st round of funding included for 2003)	17	€0.97M (over 3 years)	UCD (2) DCU(2) & NCSR(1) UCC (4) & NMRC (1) UL (4) & MSSI (2) NUI May (1)
Basic (including closely related areas) 5	5	€0.69M	UCC (1) & NMRC (3) DCU (1)
Postdoctoral	4	€0.31	DCU, UL, UCD (2)
Total	**22**	**€1.97M**	

3. Science Foundation Ireland – September 2003

Institution	Investigator	Award €	Project Title
TCD	Prof John Pethica	6,348,690	Nanostructures and Molecule Mechanics
TCD	Prof. Igor Shvets	7,246,149	Studies of Surfaces and Interfaces o Magnetic Spinel Oxides
TCD	Prof. Michael Coey	7,066,937	Conception and Implementation o Nanoscale Spin Electronics (CINSE)
TCD	Prof. John Boland	7,762,077	Atomtronics: Nanoscale Science and Technology for Future Information
TCD	Dr. Stefano Sanvito	926,705	Computational Spintronics at the Molecular Level
TCD	Prof. Werner Blau	878,460	Applications of Carbon Nanotubes and Self-Assembling Molecular Nanowires in Electronic and Optoelectronic Devices
TCD	Prof. John Pethica CSET- DA	250,000	Centre for Research on Adaptive Nanostructures and Nanodevices
TCD	Dr. Suzy Jarvis	3,735,000	The function of nanoscale complex systems
CIT	Dr. Sile Nic Chormaic	(€)711,049	Investigation of Active and Passive Sherical Glass Microresonators for Advancements in Telecommunications and Quantum Information Technology
DCU	Prof. Gordon Wallace	(€)119,527	Novel Micropatterned Platforms Utilising Inherently Conducting Polymers
NUIG	Dr. Alan Ryder	944,563	Nanoscale Biophotonics: Novel Approaches to Ultra-Sensitive and High Accuracy Fluorescence Techniques

UCD	Prof. Donald Fitzmaurice	961,000	Using High-Information Content Molecules to Template the Self Assembly in Solution and Self Organisation at Patterned Substrates of Functional Nanoscale Components and Devices Incorporating Asymmetric Nanoparticles
UCC	Dr Guillaume Huyet	1,771,900	Nonlinear Dynamics and Quantum Optics of Semiconductor lasers for Phototonic Applications
NMRC	Dr. Jim Greer	999,240	Properties of Oxide Semiconductor Structures
NMRC	Prof. Clivia Sotomayor Torres	3,333,150	Silicon-based photonic circuits containing 2- and 3-dimensional photonic crystal waveguids.
Total (Over 4-5yrs)		**45,860,717**	

4. Higher Education Authority - PRTLI

Programme	Institution/Project	Capital/ Building	Recurrent	Total	Collaborators
	NMRC Fundamental Physics of Quantum Semiconductor Devices	30,000	120,000	150,000	
	UL (MSSI) (18% of total)			171,450	
	NMRC UCC CIT Nanoscale Science & Technology Initiative/ National Nanofabrication Facility	11,884,748 362,891 106,658	200,873	12,085,621 362,891 106,658	
	TCD (Institute of Advanced Materials Science, IAMS)	10,502,004	464,724	10,966,728	
	WIT, ITT (3% of total)			60,300	
	DIT (FOCAS)			2,889,924	
	DCU (NCSR)			1,663,357	ITT
	DCU (NCPST)			916,751	ITT
PRTLI Cycle 3	NMRC UCC Nanoscience	12,012,810* 1,193,296**	602,618 1,357,350	12,615,428 2,550,646	
	TCD (Institute of Advanced Materials Science, IAMS)	471,240	3,211,000	3,682,240	DCU
	WIT, ITT, LIT, NUIG, UCC (under Atlantic University Alliance)			634,869	
Total				**48,856,863**	

5. European Union Funding via Framework Programme 5: 1998 - 2002

Institution(s)	Project Ref. Number	Award €m	Project Title
DE BEERS INDUSTR DIAMOND DIV (IRL)	2001-40737-GRD1	0.11	Field Assisted Sintering Technology for the Densification of Nanostructured Powders and Fabrication of Funtionally Graded Materials
GEM PLASTICS	CRAF-1999-70433	0.04	NANOADD
NANOCOMMS LTD	PL00-30346	0.12	Optical Amplification on Polymer Based Material and Devices
NMRC	IST-1999-11974	0.31	Biomolecule driven assembly of nanoparticle based electronic devices.
NMRC	HPRN-CT-2000-00028	0.20	Self-Assembly of Addressable and Modulatable Arrays of Functional Metal Oxide Nanocrystals
NMRC	IST-2000-29295	0.384666	High K Dielectric Simulation
NMRC	IST-1999-10828	0.202514	Nanotechnology Computer Aided Design
NMRC	HPRN-CT-1999-00048	0.241999	Linking micro & nanotechnology cad tools to conventional packages
NMRC	IST-1999-11617	0.110805	A Study for the Construction of a Quantum Information Processing Device using Doped Fullerenes
NMRC	IST-2001-37150	0.143780	Read-out of a Single Electron Spin
NMRC	IST-1999-29111	0.36	Nanoscale Integrated Circuits Using Endohedral Fullerenes
NMRC	PL00-30346	0.43	Optical Amplification on Polymer Based Material and Devices

NMRC	QLK3-CT-2001-01982	0.376	Novel Genechip Technology for Simplified Detection of Molecularly Heterogeneous Genetic Diseases: Detection of Cystic Fibrosis as a Model
NUIM	IST-1999-11617	0.110805	A Study for the Construction of a Quantum Information Processing Device using Doped Fullerenes
NUIM	IST-2001-37150	0.143780	Read-out of a Single Electron Spin
PALFAB LTD	GTC1-1999-10009	0.03	Wood Modification, the Novel Base, Providing Materials with Superior Qualities Without Toxic Residue
TCD	HPRN-CT-2000-00128	0.25	Coupled mechanical and electronic properties of carbon nanotubes based systems
TCD	IST-1999-10849	0.4	Magnetic Films for MEMS applications
TCD	HPRN-CT-2000-00037	0.25	Large Scale Synthesis of Carbon Nanotubes and their Composite Materials
TCD	PL28052	0.13	Carbon Nanotubes for Future Industrial Composites; Theoretical Potential Versus Immediate Application
TCD	GRD1-1999-10470	0.33	Scanning Probe Research on Nanoscale Magnetism of Advanced Materials for Hig Resolution Recording
TCD	CRAF-1999-70433	0.37	NANOADD
UCC	IST-2000-25469	0.10	Intelligent Image Displays
UCD	IST-1999-11974	0.28	Biomolecule driven assembly of nanoparticle based electronic devices.

UCD	HPMD-CT-2000-00014	0.45	Characterisation Biologically Assembled Nanoparticle-Based Devices by Scanning-Probe and Electron Microscopies
UCD	HPRN-CT-2000-00028	0.20	Self-Assembly of Addressable and Modulatable Arrays of Functional Metal Oxide Nanocrystals
UL	GTC1-1999-10009	0.03	Wood Modification, he Novel Base, Providing Materials with Superior Qualities Without Toxic Residue
UL	GRD2-50114-2001	0.22	Nanostructures Sulphur Traps for the protection of high performance NOx storage/ reduction catalysts in low emission engine applications
Waterford Institute of Technology	HPRN-CT-2000-000388	0.25	Manufacture and Characterisation of Nanostructured Al Alloys
Total		**6.57**	
Total (excluding companies)		**6.27**	

NB For selected EU projects (highlighted in blue), only total project funding was available. Grants were then estimated as €400k per project and €250k per training network (HPRNs).

APPENDIX VII

ROLE OF THE NATIONAL NANOTECHNOLOGY FORUM

Overview

Specifically, the forum could address the following, in the interests of co-ordination and sharing of information for best practice and effectiveness:-

- Objectives, funding and measurement

The definition of objectives for what funding organisations wish to achieve (no. of R&D centres, amount of foreign investment) and the identification and co-ordination of the relevant activities to ensure these objectives are being met;

- Knowledge creation (which includes the physical infrastructure to enable world-class basic research, exploration of applications, developments and commercialisation of innovations);

- Knowledge transfer between research centres and industry;

- The attraction or extension of MNCs;

- The development of Irish enterprise underpinned by the varying and relevant mixes of public and private funding;

- The development of Private funding within the context of the entire value chain and public funding. There should be in effect, a hand shaking between public and private funding and as one recedes in the value chain, the other will increase.

Stock Takes of Activity

There should be a regular and published stock take of nanotechnology related activities underway and capital expenditure in Ireland. This stock take should operate to inform all stakeholders on activities, results, and possibilities. Monitoring of investment should be smart, interactive and additive and Return on Investment should be linked to economic return in terms of job creation, skills development, capability development etc. This will mean that public investment will need to be divided between short term and long-term investments.

Communications

Communications is an essential aspect to educate and inform on what nanotechnology is, how it operates and what can be achieved. All aspects of measurements and stock takes should be structured and communicated to all stakeholders in Ireland – SMEs, MNCs, Policy Makers, Funders (private and public), Department of Enterprise, Trade and Employment and development agencies. This communications should be aimed at developing specific relationships between academia and SMEs/MNCs based on commercial needs and requirements. Communications can take place through both public and private sector initiatives.

Intellectual Property

There is a need to improve the Intellectual Property framework so that it fosters and nourishes development and innovation. IP is problematic in Ireland. In order to structure, nourish and foster developments knowledge creators (such as universities) should be measured on the amplification and communication of knowledge and not on IP creation. Additionally, the complexity of the area is not totally dependent on patents or copyrights. Items such as trade secrets or other mechanisms can be of value utilisation, where appropriate should be encouraged.

European Framework Programmes

The Forum should co-ordinate the input of Irish nanotechnology interests into the European Commission Framework Programmes. There is much good work happening in this area and the NNF should ensure that Ireland influences the structures of FP 7/8 and that there must be a push to get the “nano-enabled” label into the terminology of FP7/8 particularly in sectors that are significant to Ireland.

Professional Development

There needs to be further development of a professional environment for researchers in Ireland. Career paths need to be defined and recognised and structured so that professional research can be perceived as a worthwhile career path within the economy.

Multinational Corporations

To continue to successfully attract MNCs R&D investment into Ireland, there is a need to:

(a) Ensure that it has a critical mass for R&D excellence within the country.

(b) Targets the R&D specialists in each MNC through leveraging the relationship of the current operation but recognising that R&D will always search for excellence. The targeting of R&D specialists will imply that Ireland will need to ensure that such specialists always meet the best R&D people from the Irish economy to ensure that their image of what is being done in Ireland is detailed and accurate.

(c) Ensure that there are sufficient incentives in place to justify the cost argument within Ireland. This specifically includes the creation of taxation-based incentives for R&D activities within Ireland.

Existing and New Indigenous Industry

The SME environment in Ireland will need to be addressed from two perspectives by the NNF.

(a) SMEs that are compelled to change through competitive or customer pressure will need the Enterprise Ireland existing funding instruments and third level supports to ensure that SMEs can "Fast track" access to the appropriate technology solution.

(b) SMEs that are inventors of new Nanotechnology solutions will need access to funding mechanisms that can be introduced to Ireland at both the public and private level. Enterprise Ireland will need to use it's funding instruments to leverage private sector investment in inventive startup SMEs.

Education

The advent of Nanotechnology and the new synergies required in research and industry will imply a specific requirement for education establishments to produce highly multidisciplinary skills that stretch across a variety of disciplines at graduate level. This will imply some changes in the teaching and development of postgraduates. It will be essential that the Irish state produce this national capability to allow the further development of resources for both MNCs and SMEs.

ICSTI MEMBERSHIP

Dr. Edward M. Walsh
(Chairman)
President Emeritus
University of Limerick

Dr. Leonora Bishop
Business Consultant

Ms. Mary Burke
Managing Director
BioClin Research Laboratories

Mr. Ian Cahill
Chairman
LM Ericsson Ltd. & Director,
National Institute of Technology
Management

Ms. Marion Coy
Director
Galway-Mayo
Institute of Technology

Mr. Martin Cronin
Chief Executive
Forfás

Ms. Mary Cryan
Director of Technology
Prospectus Strategy Consultants

Dr. Ann Cullinane
Head, Virology Unit
Irish Equine Foundation Ltd.

Prof. Donald Fitzmaurice
Solar Technology Group
Chemistry Dept., National
University of Ireland, Dublin

Dr. Peter Heffernan
Chief Executive
Marine Institute

Mr. Paul Holden
Managing Director
Rédacteurs Ltd.

Dr. Mike Hopkins
Physicist Scientist
Plasma Research Laboratory,
Dublin City University

Dr. Brendan Hughes
Director of Drug Development
Wyeth Medica Ireland
Development Facility

Ms. Josephine Lynch
Secretary to Council
Forfás

Prof. Tom McCarthy
Dean of the Business School
Dublin City University

Prof. Anita R. Maguire
Dept. of Chemistry
National University of Ireland,
Cork

Dr. David Melody
Formerly Vice President for R&D
(Formerly) Loctite (Ireland) Ltd.

Dr. Pierre Meulien
Chief Executive
Dublin Molecular Medicine Centre

Dr. Pat Morgan
Dean, Faculty of Science
National University of Ireland, Galway

Dr. Mike Peirce
Chairman
Mentec Ltd.

Dr. Ena Prosser
Director
BioResearch Directorate, Enterprise Ireland

Prof. William J Reville
Biochemistry Dept.
National University of Ireland, Cork

Prof. James A. Slevin
Science Secretary Royal Irish Academy

Dr. Don Thornhill
Chairman
Higher Education Authority

Dr. Ena Walsh
Head of Operations and Business Development
Centre for Human Proteomics, Royal College of Surgeons in Ireland

ICSTI STATEMENTS (1997 - 2004)*

Title of Statement	Date of Publication
National Code of Practice for Intellectual Property from Publicly Funded Research	Jan. 2004
EU Debate on the Role of Fundamental Research	Nov. 2003
A Comparison of Starting Salaries for Science Graduates and Engineers	Aug. 2003
State Funding Priorities for 2004	July 2003
Utilising Intellectual Property for Competitive Advantage	Feb. 2003
Embedding the PharmaChem Industry in Ireland	Feb. 2003
Design and Development	Sept. 2002
Measuring and Evaluating Research	Aug. 2002
Report on Biotechnology	Feb. 2002
Commercialisation of Publicly Funded Research	Feb. 2001
Benchmarking School Science, Technology and Mathematics Education in Ireland Against International Good Practice	Feb. 2000
Science in Second Level Schools	Nov. 1999
Public Sector Research and Technology Services for Innovation in Enterprises	Sept. 1999
Technology Foresight Ireland	April 1999
Investing in Research, Technology and Innovation (RTI) in the Period 2000 to 2006	Mar. 1999
State Expenditure Priorities for 1999	Nov. 1998
Science Technology and Innovation Culture	Nov. 1998
Innovation in Enterprises in Ireland	July 1998
Mechanisms for Prioritisation of State Expenditures on Science and Technology	June 1998
Science in Primary Schools	May 1998

A Partnership Approach to Research Funding – The Need for a National Science and Engineering Board	May 1998
£250 million Scientific and Technological Education (Investment) Fund	Jan. 1998
State Expenditure Priorities for 1998	Sept. 1997

***A CD of ICSTI Statements published between 1997 and 2001 is available from the ICSTI Secretariat.**

ICSTI SECRETARIAT

The ICSTI Secretariat is provided by Forfás, the national policy and advisory board for enterprise, trade, science, technology and innovation.

Correspondence should be addressed to:

The ICSTI Secretariat
Wilton Park House
Wilton Place
Dublin 2
Ireland

Other contact details are:

Tel: +353 1 607 3186
Fax: +353 1 607 3260
E-mail: icsti@forfas.ie

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