MINISTRY OF RESEARCH SCIENCE + TECHNOLOGY

MoRST

TE MANATŪ PŪTAIAO

nanoscience + nanotechnologies

ROADMAPS for SCIENCE

What is a Roadmap?

This is one of a series of Roadmaps for Science , designed to guide New Zealand s science and research activity. Roadmaps are a type of strategy, providing broad context and high level directions on a particular area of science from a New Zealand perspective.

Roadmaps represent the Government s position on the science, noting how our science capabilities should develop to best meet New Zealand s future needs. These are not technological roadmaps, with milestones, targets or detailed research plans. Those details need to be decided by those with the responsibility for funding particular pieces of research, in conjunction with the end-users of research.

These Roadmaps set the context for the detailed work of the Foundation for Research, Science and Technology and the Health Research Council. The Foundation, for example, will work with relevant stakeholders to identify the key research questions at a level of detail below each Roadmap.

By producing these Roadmaps the Ministry of Research, Science and Technology is ensuring that the strategic research investment that makes up a significant part of Vote RS&T goes to those areas that will make the most difference for New Zealand over the long term.

The Roadmaps also set the scene for better co-ordination across government. The directions in each Roadmap not only highlight the areas of science we need to build but also the future skills and connections we need to make.

Ministry of Research, Science and Technology
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ROADMAPS *for* SCIENCE

A GUIDE FOR **NEW ZEALAND SCIENCE ACTIVITY**

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Preface

The Government recognises the critical role science and innovation have in driving New Zealand's transformation to a high-value, knowledge-based economy and society. Our focus has been on ensuring research, science and technology delivers on their potential as drivers of economic, social and environmental improvement.

One of our priorities has been establishing long-term directions for the science sector. We have already set priorities to guide our investment in RS&T, but we recognise we can do better. This will ensure New Zealand is well positioned to identify future research programmes and direct our efforts towards meeting our long-term needs.

Nanotechnology is an emerging area of science and technology that represents significant opportunities for New Zealand. As this Roadmap points out, New Zealand needs to be "well poised" to take advantage of future developments and to meet challenges associated with this suite of technologies. This document provides the guidance to ensure we develop the capabilities that are necessary to responsibly develop and manage nanoscience and nanotechnologies in New Zealand.

The Roadmaps for Science series represents an important step in providing more explicit guidance on science directions. They cover areas of scientific and technological research and development that present significant opportunities for New Zealand and where we feel more direction will help us make the most of those opportunities.

Over the coming months and years we will be introducing Roadmaps in other areas of science where we see a need for them.

The Roadmaps for Science will serve us well in ensuring research, science and technology provide a strong platform for an innovative and prosperous New Zealand.

Hon Steve Maharey, Minister of Research, Science and Technology

Summary

Nanoscience and nanotechnologies are providing us with new understanding of atomic and molecular properties and processes. This understanding is predicted to lead to transformational developments across a wide range of sectors and industries. Convergence of nanotechnologies with other fields, such as biotechnology and information and communication technology (ICT), is expected to lead to significant economic, environmental and social opportunities and challenges.

There is no accepted universal definition of what nanotechnology is. For the purposes of this Roadmap, the definition provided by the United States' National Nanotechnology Initiative is used:

"[Nanotechnology is] the understanding and control of matter at dimensions of roughly 1 to 100 nanometres[1], where unique phenomena enable novel applications."

This Roadmap discusses both nanotechnology and nanoscience. Nanoscience focuses on the understanding of properties at the nanoscale. Nanotechnology involves the design, characterisation, production or amplification of structures, devices and systems by controlling shape and size at nanometre scale.

Internationally, the major foci of nano-research are creating nanomaterials, understanding the properties of them and developing nanoscale devices. In New Zealand particular nanoscience capability is developing in nanoelectronic devices, materials for industrial uses, and methods for creating and characterising nanomaterials. Capabilities in bio-nanotechnologies are also beginning to emerge.

The New Zealand government currently invests, at most, $11 million per year in projects involving aspects of nanoscience and nanotechnologies. Actual nanoscale research and development (R&D) may represent $6 million of this. Most of the investment comes from the New Economy Research Fund managed by the Foundation for Research, Science and Technology (FRST). The MacDiarmid Institute for Advanced Materials and Nanotechnology, one of the Centres of Research Excellence funded by Vote Education, is also an important source of nanoscience funding. Several of the Crown Research Institutes (CRIs) are also using some of their Capability Fund allocations to develop nanotechnology capability.

Nanoscience and nanotechnologies are relatively new fields of scientific inquiry, yet many countries are investing substantial amounts of money in them. Much of the current nano-related research being done around the world is basic research rather than direct responses to industry or market needs. Current applications tend to enhance existing consumer products. A range of science, technological and marketing challenges need to be overcome before revolutionary applications of nanotechnologies can develop. There is much uncertainty over what will emerge.

1 A nanometre (nm) is 10^{-9} metres and encompasses the realm of many atoms and molecules. As a comparison, a human hair is typically 80,000 nm wide and the two strands of a DNA double helix measure 2.5 nm across.

As with other new technologies, nanotechnology is generating concern about its impact on individuals, society and the environment. As nanotechnologies are at an early stage of development there are opportunities for public discussion on how they can best meet society's needs and expectations. This Roadmap notes the need to encourage and support public discussions on nanotechnologies.

Much of New Zealand's current nanoscale research is more likely to be commercialised elsewhere. The opportunities for New Zealand-led innovation at the nanoscale need to be grasped. This is especially the case in sectors where New Zealand has existing competitive advantage and where existing research strengths can help establish new advantages. To do this, New Zealand needs to increase capability in nanoscience and nanotechnologies so that the capacity exists to maximise the benefits and minimise the risks associated with these fields.

This Roadmap is designed to inform readers of national and international developments and to prepare for the likely challenges and opportunities resulting. To that end, the Roadmap sets the following goal:

To enhance research, private sector, and government capabilities to absorb, develop and apply nanoscience and nanotechnologies for the benefit of New Zealand.

Three objectives underpin this goal:

- Nanoscience and nanotechnologies should be developed and managed responsibly.
- Nanoscience and nanotechnologies should contribute to economic transformation through higher productivity, higher value products and diversifying the economy.
- Nanoscience and nanotechnologies should contribute to sustainable development and social well-being.

Nine directions provide the Government's view of the way we should approach these objectives. There are three overarching directions:

- Until 2010 the main focus for investment in nanoscience and nanotechnologies should remain on basic research that builds capability and critical mass.
- Additional investment in the medium term (to 2015) should be targeted to research that shows strong relevance and benefit to existing industries.
- In the longer term a greater proportion of investment should be targeted to supporting research and development that has more transformative application potential.

Six other directions underpin these:

- Greater emphasis should be placed on building capability in bio-nanotechnologies.
- The needs of New Zealand's existing industries should inform research in nanoscience and nanotechnologies.
- The Government will work to ensure the appropriate tools and skills are available to underpin the research directions.
- Social research should inform New Zealand's nano-related research and policy.
- The Government will support inclusive forms of public engagement that enable communities to contribute to decisions on nanoscience and nanotechnology applications.
- The Government will ensure that regulatory arrangements are appropriate for managing nanoscience and nanotechnologies.

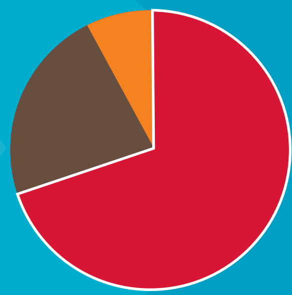
This Roadmap identifies a series of actions to start us moving in these directions. The Ministry of Research, Science and Technology (MoRST) will keep the directions and actions under review, track indicators of progress, and advise the Government on the need to refresh directions by 2011.

nanoscience + nanotechnologies

Funding Evolution

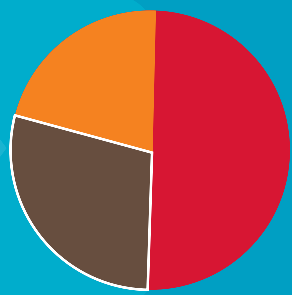
2006 to 2010

DIRECTION ONE
Focus on basic research



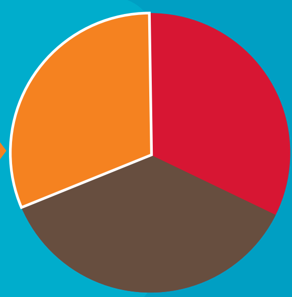
2010 to 2015

DIRECTION TWO
Increase focus on relevance to existing New Zealand industries



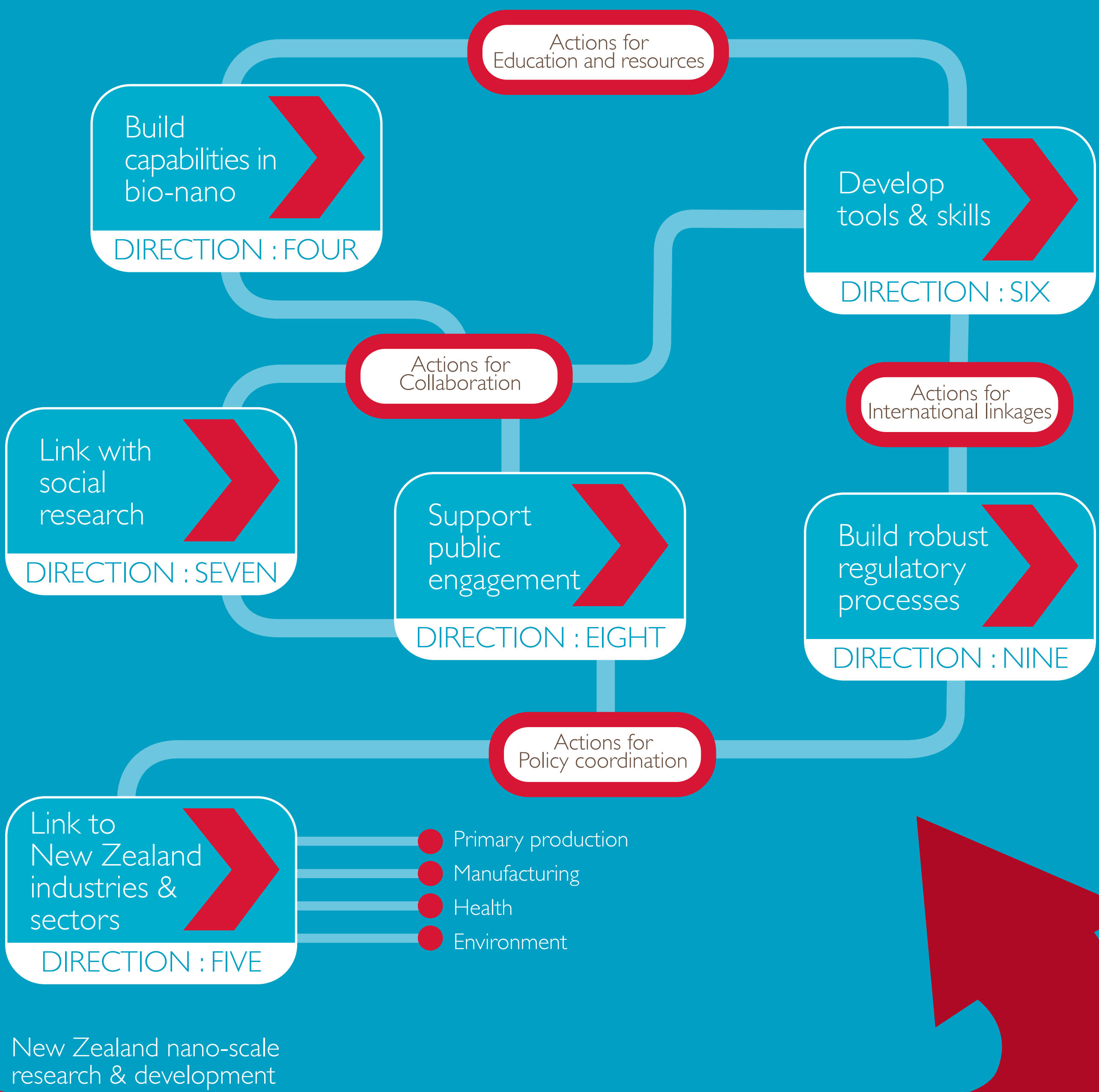
beyond 2015

DIRECTION THREE
Increase focus on more transformative applications



ROADMAPS for SCIENCE

New Zealand Context: Enhance New Zealand nanotechnology capabilities & absorptive capacity



Global Context:

- Nanotechnology at early stage of development
- Developing international standards & methodologies
- Convergence with other technologies
- Nanotechnology being increasingly used to enhance existing products and processes
- Revolutionary applications still to emerge

The directions are :

2006 to 2010 | 1 | Basic research that contributes to the understanding and exploitation of novel properties that emerge at micro- and nanoscales and builds critical mass. Pg 43

2010 to 2015 | 2 | Research targeted to proposals that show strong relevance and benefit to existing industries. Pg 43

beyond 2015 | 3 | Development of more transformative applications that may lead to the formation of new industries. Pg 43

other directions | 4 | Build capabilities in bio-nanotechnologies. Pg 43

other directions | 5 | The needs of existing New Zealand industries should inform research. Pg 43

other directions | 6 | Ensure the appropriate tools and skills are available to underpin the research directions. Pg 47

other directions | 7 | Nano-related research and policy should be informed by social research. Pg 49

other directions | 8 | Support development of inclusive forms of public engagement. Pg 49

other directions | 9 | Ensure that regulatory arrangements are appropriate. Pg 53

MoRST will keep the directions and actions under review, tracking indicators of progress, and advise the Government on the need to refresh directions by 2011.

1 Introduction

1.1 Why a nanoscience and nanotechnologies roadmap?

The emerging area of nanoscience and nanotechnologies has features that make producing a Roadmap worthwhile:

- Nanoscience and nanotechnologies are expected to impact on a very broad range of sectors over the coming decades. This Roadmap sketches out the main impacts for New Zealand.
- New Zealand will not be able to invest in the full range of R&D associated with nanoscience and nanotechnologies, or compete effectively in most areas of application. This Roadmap begins to identify key research areas and strategic opportunities.
- Some potential applications of nanoscience and nanotechnologies raise safety, ethical and other social concerns. This Roadmap points to the need to prepare for these at early stages of development.

1.2 This Roadmap

The audiences for this Roadmap include:

- funding and investment agents with responsibility for investing in publicly funded research, notabley FRST and the Health Research Council (HRC);
- government agencies responsible for safety regulation and ethical oversight of nanoscience;
- research communities involved in nanoscience and nanotechnologies (biological, engineering, chemical, physical and social scientists); and
- industries and sectors that may benefit from, or otherwise be affected by, the uptake of nanotechnologies.

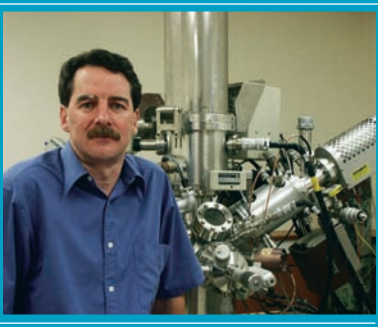
This Roadmap has been developed by MoRST. In preparing this Roadmap we have:

- drawn from a report on nanotechnology by the Bioethics Council published in 2003[2];
- developed thinking about the opportunities and challenges of nanoscience and nanotechnologies initiated in a FRST symposium held in February 2005;
- drawn information from a range of national and international research and policy reports (listed in Annex 1);
- worked closely with a steering group[3] that has advised on context, issues and directions;
- held a workshop in November 2005 involving nanoscience and nanotechnology researchers to identify New Zealand science capabilities in the area; and
- incorporated comments from interested parties on an earlier draft of this Roadmap (May 2006).

2 Bioethics Council (2003). "Nanotechnology Report of the Toi Te Taiao: Bioethics Council to the Minister for the Environment." Available from http://www.bioethics.org.nz/

3 Representatives were from the University of Canterbury, Industrial Research Ltd, Scion, New Zealand Trade and Enterprise, Ministry for the Environment, Environmental Risk Management Authority, Foundation for Research, Science and Technology, and an independent consultant.

A new semiconductor and UV protection



Professor Jim Metson in the Advanced Materials Research Centre at the University of Auckland. The impressive piece of hardware to the right is a Secondary Ion Mass Spectrometer, used for analysing surfaces.

Professor Jim Metson, Leader of the Materials Cluster, in the University of Auckland's Department of Chemistry, says research by their laboratory, and collaborative research by other groups in New Zealand, is shedding new light on the properties of nano Zinc Oxide (ZnO).

Prof Metson says that other international researchers are focusing on the antibacterial characteristics and physical stability of nano ZnO, which make it an effective antibacterial agent. "At the nano-scale, ZnO has unique characteristics. It does not discolor, nor does it require ultra-violet exposure to induce activation. These properties make nano ZnO a superior non-organic antibacterial agent.

"In the cosmetics industry, typical ZnO formulations appear white when applied on the skin – this is not popular with consumers, so standard ZnO is not widely used as a UV blocking agent. Nano ZnO, however, shows excellent ability in resisting UVA and UVB and is largely transparent. Commercial sunscreen products have already snapped up the use of nano ZnO."

Prof Metson explains that his research team have taken quite a different tack. "Our group are examining several semiconductor and screening properties of materials incorporating nano-scale ZnO particles. These materials offer UV protection of polymers and timbers, while films of ZnO have direct semiconductor applications."

"I believe the big potential, including opportunities for New Zealand, is in the use of nano-scale ZnO films. Although other international research groups have turned their attention on the semiconductor possibilities of nano ZnO, we've been putting a lot of unique work into implantation and controlling the electrical properties in thin films. Nano ZnO may be used in composites with plastics, pigments and fibers in various kinds of products, offering benefits such as anti-static, electromagnetic-shielding and UV-blocking.

"Nano ZnO is an interesting material with real potential to harness it in sensors and flat panel applications. I believe that we will find an ideal niche somewhere in this area. From a New Zealand base you need to either find a solid market niche where you can stay ahead of the game, or you need to form partnerships with the predators - both are tough."

Prof Metson says that the research could result in New Zealand developing the technology for the application of nano ZnO components in specialised semiconductor devices such as solid state sensors and sensor arrays.

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2 International context

Section summary

- Nanoscience and nanotechnologies are emerging fields of science and technology, defined by their focus on nanoscale (1 to 100 nanometres) and the 'novel properties' that emerge at this nanoscale.
- Nanoscience and nanotechnologies are seen as enabling sciences and technologies. They are providing new understanding of atomic and molecular properties and processes and are predicted to lead to transformational developments across a range of sectors or industries including manufacturing, electronics, energy, medicine, food, primary production, environment and defence. Convergence of nanotechnologies with other fields, such as biotechnology and ICT, will also be significant.
- The major foci of current research are creating nanomaterials, understanding the properties and developing nanoscale devices.
- International investment in nanoscience and nanotechnologies is around US$4 billion per annum and likely to continue increasing.
- Key challenges associated with nanoscience and nanotechnologies include development of applications, ensuring the adequacy of regulatory systems, and enabling early and constructive engagement with society on the associated risks and benefits.

2.1 What are nanoscience and nanotechnologies?

There are a range of definitions for what nanotechnology is but currently there is no accepted universal definition. We follow the United States' National Nanotechnology Initiative definition[4] as well as adopting the distinctions between nanoscience and nanotechnologies used by the United Kingdom's Royal Society and Royal Academy of Engineering[5].

Definition of nanotechnology

"the understanding and control of matter at dimensions of roughly 1 to 100 nanometres, where unique phenomena enable novel applications."

Nanoscience focuses on the understanding of properties at the nanoscale, while nanotechnology involves the design, characterisation, production or amplification of structures, devices and systems by controlling shape and size at nanometre scale. The use of the plural "nanotechnologies" underlines the fact that there are a range of technologies and potential applications involved in this area.

4 See http://www.nano.gov/html/facts/whatIsNano.html

5 See http://www.nanotec.org.uk

The definition of nanotechnology focuses on both the size and the unique phenomena or novel properties that emerge at, or near, the nanoscale. The nanoscale is strictly between 1 and 100 nanometres (nm; 10^{-9} metres), and encompasses the realm of many atoms and molecules. As a comparison, a human hair is typically 80,000 nm wide and the two strands of a DNA double helix measure 2.5 nm across. The nanoscale can involve principally one dimension (such as associated with coatings and films), two (such as nanowires and nanotubes) or three dimensions (such as nanoparticles).

The inclusion of "unique phenomena" in the definition is important since it differentiates nanoscience and nanotechnologies from a range of already well established disciplines (such as biochemistry) that may also involve nano-sized systems or objects but not necessarily have unique properties related to their size. The "unique phenomena" are also the aspect of nanoscience and nanotechnologies that promise the revolutionary or transformational developments. These also offer the greatest challenges to scientific understanding, economic opportunities and society at large.

The novel properties emerge due to increased relative surface area and/or to quantum effects[6]. Novel properties will, for example, manifest as changes in mechanical, electromagnetic and/or optical properties. As an illustration, gold is an inert material in its common bulk form, but becomes reactive at the nanoscale. There is not a magic transition at 100 nm, so inclusion in the definition of novel properties is required; some novel properties may emerge above 100 nm, and others below it.

Using this definition, examples of nanoscience or nanotechnology include the:

- study of properties of nanoscaled structures or surfaces;
- study or manipulation of biological molecules, structures or processes using tools and concepts of nanotechnology; and
- manufacture of materials with nano-size dimensions and structures with nanoscaled features.

2.2 Why so much interest?

Nanoscience and nanotechnologies are of interest because they involve the study and manipulation of materials at the molecular or atomic level in a more detailed or controlled way than previously possible. Some forms of chemistry and manufacturing involving the nanoscale have been undertaken for centuries, such as the manufacture of stained glass. However, it is only in the last 30 years through the development of new tools, such as the scanning electron and atomic force microscopes, that it has been possible to have a greater degree of control at the nanoscale. A lay person's overview of issues associated with nanoscience and nanotechnologies can be found in *The Economist magazine*, 1 January 2005 edition.

Being involved in the control of the fundamentals of matter, nanotechnologies have the potential to be revolutionary as well as evolutionary. Revolutionary developments could bring, for example, new manufacturing processes or multi-functional drug delivery devices that target specific cells. Evolutionary developments could improve properties, such as strength and/or flexibility, of existing materials and increase efficiency of manufacturing processes. Molecular biology provided new means for studying and manipulating cells and organisms. Similarly, nanoscience and nanotechnologies are opening up new ways of studying and manipulating a much broader range of materials and processes. It is, therefore, not unrealistic to expect that the implications of nanoscience and nanotechnologies will be at least as profound as those resulting from molecular biology.

The properties and behaviour of nanoscale particles and structures can be very different from those observed at the micro-scale. This is opening up new opportunities to study chemical, physical and biological phenomena, and to develop new or improved applications in a broad

6 Quantum effects relate to phenomena at the atomic level where "classical" theories, such as Newtonian mechanics and electromagnetism, do not operate.

range of fields. The range and types of applications envisaged indicate that some nanotechnologies are likely to have much greater implications and impacts on businesses and society than biotechnology.

Nanoscience and nanotechnologies touch on a diverse range of disciplines – physics, chemistry, biology, engineering, design, social science, and ICT. Of particular significance is the anticipated convergence between nanotechnologies, biotechnologies and ICT that will lead to an enhanced range of applications and possibilities.

Nanotechnologies will not comprise a single industry sector. Rather they are a group of "enabling" technologies that will influence a range of fields. In many cases there will not be "nanotech products" as such, but products and process that involve and/or incorporate nanoscience or nanotechnologies. Many applications involving nanoscience or nanotechnologies will require R&D above the nanoscale to produce useful applications. For example, a micro-fluidic device may use nano-structured surfaces to control fluid flow, but other R&D at larger scales will be required to produce a functional device.

Understanding the properties or structures of materials and processes at the nanoscale can also lead to product and process innovations without incorporating nanotechnology into the final product or process. For example, studying food processing techniques at the nanoscale could lead to better processing protocols and use of raw materials[7].

The potentially revolutionary aspects of nanotechnologies are attracting the attention of governments, non-governmental organisations, industries and researchers both because of opportunities they may provide as well as challenges that they raise. These interests cover economic, social, environmental and knowledge consequences of particular technologies and applications. Some of these are discussed later.

A range of high level international fora are already discussing potential implications of nanotechnologies:

- The Organisation for Economic Cooperation and Development's (OECD) Chemicals Committee has established a Working Party on Manufactured Nanomaterials. This Working Party will address issues associated with human health and environmental safety, particularly for the industrial chemicals sector.
- The Industrial Science and Technology Working Group of Asia-Pacific Economic Cooperation (APEC) is undertaking a pilot study to develop standardised nanoscale analytical and measurement methods.
- The Asia Nano Forum is a network organisation established to promote excellence in research, development and the economic uptake of nanotechnology within the Asian region.
- The International Organization for Standardization has established a technical committee on nanotechnology to consider standard setting for measuring and characterising at the nanoscale.
- UNESCO has taken an interest in ethical issues associated with nanotechnologies.
- An International Dialogue on Responsible Development of Nanotechnologies is debating how to ensure appropriate regulation and community engagement associated with nanotechnologies.

7 See the Institute of Food Science & Technology's information statement on nanotechnology (February 2006). Available at http://www.ifst.org/site/cms/contentChapterView.asp?chapter=1

2.3 Opportunities for nanoscience and nanotechnologies

Nanoscience and nanotechnologies are still at an early stage of research and development. Research is strongly investigator-led with most investment directed toward improving the understanding of nanoscale phenomena and processes and creating new materials or structures.

There are, however, strong economic drivers that internationally are leading to increased and targeted investment into fundamental research. Some reports refer to nanotechnology products generating a trillion dollars in the USA by 2015, but the basis for this prediction is very uncertain. Nonetheless, the potential of nanoscience and nanotechnologies to increase the productivity and/or product value of a range of existing industries, create new manufacturing industries, and to contribute to more sustainable development, are being widely recognised. Annex 2 summarises international government investments in nanotechnologies. Such national investment is usually focussed on areas that are anticipated to support existing research and/or industrial strengths, such as electronics industries in some Asian countries, chemical companies in Europe and the USA, and the automotive industry in Germany.

In some of the larger industrialised nations approximately one-third of the investment appears to be from government sources (similar to the trend for total R&D investment). However, comparisons are difficult because there is no standard definition of nanotechnology, or consistency in what countries include in their R&D expenditures. Nonetheless, several governments have made significant investments in nanotech R&D in the last five years and this trend is likely to continue (PCAST 2005[8]).

Currently, key sectors with interests in nanotechnologies are those related to the electronics, ICT, manufacturing, medical and defence industries. Food and agricultural sectors, along with the textile industry, are also developing an interest in the nanoscale.

Figure 1 illustrates some of the potential areas and types of applications. More detailed examples can be found in a range of sources, such as the National Nanotech Initiative[9], the Royal Society and Royal Academy of Engineering[10], the OECD[11], and the Woodrow Wilson International Center for Scholars[12].

8 http://www.nano.gov/FINAL_PCAST_NANO_REPORT.pdf

9 http://www.nano.gov/

10 http://www.nanotec.org.uk

11 See the "Small sizes that matter" report. Available at http://www.oecd.org/dataoecd/4/38/35081968.pdf

12 See the "Nanotechnology Consumer Products Inventory." Available at http://www.nanotechproject.org/index.php?id=44

Figure 1

Examples of anticipated areas and types of applications for nanotechnologies, such as medical and diagnostics, respectively. Convergences between applications in some areas, such as drug delivery and therapeutics, imaging and diagnostics, are likely. Not shown are tools and measurement protocols for creating and studying nanoscale materials and features.

A range of nanotechnology consumer products are already available around the world (see Table 1). These have generally enhanced existing products rather than provided revolutionary new developments. Electronic, ICT and material applications currently appear to be areas where initial major advances are, or will, be made. Some medical applications are also possible in the near term. For example, use of nanomaterials for tissue regeneration and in diagnostic and drug delivery devices.

Table 1

Examples of current and anticipated near term applications of nanotechnologies.

Current applications	Possible near term (five years) applications
Computer chip components (nanoscaled circuitry).	Pesticides with nanocapsules that aid uptake or timed release.
Sunscreens (nanoscale zinc oxides and titanium dioxides that more efficiently absorb ultraviolet rays).	Food packaging that improves shelf life and/or indicates freshness.
Fuel additive (Cerium (IV) oxide) to burn fuel more efficiently.	Tougher composite coatings containing carbon nanotubes for car bumpers.
Water or stain repellent clothing.	Lower energy consuming field effect display television sets using carbon nanotubes.
Anti-microbial wound dressings (containing silver nanoparticles).	Medical imaging devices using nanoscaled particles.
Tennis balls (clay nanoparticles in core reduce air loss and double ball's life).	More effective water or waste filtration devices using nano-structured filters.

Information on other current consumer applications is available from the Woodrow Wilson International Center for Scholars Project on emerging nanotechnologies.
See http://www.nanotechproject.org/.

Annex 3 lists examples of freely available sector reports that evaluate how nanoscience and nanotechnologies contribute to particular sectors. Many of these reports emphasise the importance of convergence across disciplines. For example, through linking nanotechnologies with ICT and/or with biology, as could occur with distributed sensors that measure a range of environmental parameters continuously and communicate with each other remotely.

Some reports have attempted to predict when certain applications will be developed. The 2005 edition of the influential "International Technology Roadmap for Semiconductors" suggests that transition to semiconductors incorporating nanotechnologies may start in 2015. A report by the Interdisciplinary Center for Technology Analysis and Forecasting surveyed expert views on developments in nano-biotechnology[13].

13 Interdisciplinary Center for Technology Analysis and Forecasting "Envisioned developments in Nanobiotechnology. Expert Survey" (December 2005). Available at http://www.ictaf.tau.ac.il/N2L_expert_survey_results.pdf

Many of the interviewees indicated that a range of biological applications are likely to be available in the next three to eight years. For example, bio-inspired materials and chips employing biomolecules.

More revolutionary applications are likely to appear in the medium to longer term (more than ten years from now). However, as illustrated by other technologies, reliably predicting when certain applications will appear is difficult, as is predicting how scientific discoveries are subsequently developed and applied.

What is certain is that substantial research and development is now underway in many countries, with developments in some fields proceeding rapidly. A report from Cientifica[14] notes that there is usually a seven year minimum time span from initial research to application. Substantial investments into nanotechnologies began in 2001 in the USA and Japan and 2003 in the European Union. Significant applications are, therefore, likely to start appearing toward the end of this decade. Realistically, more revolutionary products may take much longer to become established for reasons discussed below.

2.4 Challenges for nanoscience and nanotechnologies

Internationally, the main challenges associated with nanoscience and nanotechnologies from a government perspective can be grouped into three categories. These are:

- developing useful applications for nanoscale phenomena;
- undertaking R&D in nanoscience and nanotechnologies in a way that pro-actively and meaningfully engages with society; and
- understanding and effectively managing the potential risks of manufactured nanomaterials.

These challenges are interrelated.

2.4.1 Developing applications

While a range of applications are emerging, much of the current nano-related R&D is basic research[15] rather than directly responding to industry or market needs. This is due to the newness of the field and the consequent need to understand the properties that emerge at the nanoscale. However, in some areas, such as medical research, there is greater clarity over needs and how nanotechnologies can contribute.

Much is being promised about the benefits and potential of nanotechnologies. However, to move from identifying and studying novel properties at the nanoscale to developing useful applications requires addressing a range of factors. Some of these are summarised in this section.

Interdisciplinary (or multi-disciplinary) research is being emphasised as a key feature of future nanoscience and nanotechnologies. For example, physical scientists are working with clinicians, engineers and designers to develop solutions for clinical needs, such as better imaging technology. There are, however, a range of challenges in establishing interdisciplinary research (National Academy of Sciences 2004)[16]. These range from researchers needing to understand the methods,

14 "Where has my money gone?" Cientifica (January 2006). See http://www.cientifica.com/

15 Basic research is defined by the OECD Frascati Manual as "experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts, without any particular application or use in view".

16 National Academy of Sciences (2004). "Facilitating interdisciplinary research". National Academy Press. Available from http://www.nap.edu/

languages and culture of researchers from a different discipline, new modes of organisation and modified reward structures, and funding and investment agents being able to properly peer review interdisciplinary research proposals. Establishing interdisciplinary research teams or collaboration is often the easy part of the process. Maintaining them in the longer term can be more challenging.

According to Lux Research[17], a nanotechnology research and advisory firm, the countries currently succeeding in commercialising nanotechnologies (the USA, Japan, South Korea and Germany) are doing so because they have both high levels of nanotechnology activity (through public and private investment) and a strong technology development track record. Lux Research notes that the UK and France have undertaken some excellent nanoscience, but for a range of reasons this has not yet resulted in many successful commercial developments.

There are a range of factors that are important for successful commercialisation. These include:

- Managerial expertise – good business managers are essential.
- Scaling up from prototypes or proof of concept – this can be expensive, difficult, and good quality control is vital.
- Marketing – buyers have to see a need for the product.
- Distribution – finding the right partners is essential.
- Intellectual property protection – there may be overlapping patents, patents may be challenged or infringed, and patent defence can be very expensive.
- Regulation – lack of an appropriate regulatory process, uncertainty over regulatory requirements, or overly stringent regulation can inhibit commercialisation.
- Uptake – market predictions may be inaccurate or users may not be able to properly use the product, see benefits from it, or object to it.

Commercialisation of new technologies can require developing solutions to both technical and marketing challenges. It may also be necessary to develop complementary innovations in other areas of the design and manufacturing processes. Innovations that are compatible with existing practices, offer other benefits and have minimum switching costs are more likely to be rapidly taken up. Radical new products, such as Kevlar[18], usually require expensive process innovations and can take between 15 and 40 years until there is significant adoption[19]. A review of nanotechnologies and the US manufacturing sector considered that the short term impact of nanotechnologies are likely to be fragmented across different sectors and involve evolutionary rather than revolutionary applications. This review also noted that manufacturing industry executives acknowledged that there are considerable technical and financial barriers associated with nanomanufacturing that need to be addressed before opportunities are more fully realised[20].

While many large corporations are developing interests in nanotechnologies, there is recognition that involving start-up companies and small and medium sized enterprises (SMEs) will have a central role to play in nanotechnology innovation and entrepreneurship[21]. However, such companies can have difficulty accessing funding and other support to help successfully commercialise their ideas and products. In addition, since nanotechnologies are a relatively new field SMEs may not be aware of the opportunities or challenges presented by them, do not have the capabilities to adopt them, or have not recognised how research can assist their business.

17 Lux Research press release November 3, 2005. "The US, Japan, South Korea, and Germany dominate in nanotechnology today – but Taiwan and China are rising". Available from http://luxresearchinc.com (Accessed 24 March 2005).

18 Kevlar is a synthetic polymer of high strength and low weight that was first commercialised in the 1970s and is now used in a variety of products and composite materials.

19 See, for example, Maine E & Garnsey E (2006). "Commercializing Generic Technology: The Case of Advanced Materials Ventures". Research Policy 35, 375-393.

20 National Center for Manufacturing Sciences and the National Science Foundation (2006). "2005 NCMS Survey of Nanotechnology in the US Manufacturing Industry". Available from http://www.ncms.org/

21 See 7th Nanoforum General Report "European support for nanotechnology small and medium-sized enterprises". December 2005. Available from http://www.nanoforum.org/

Entangled intellectual property, such as broad patent claims with no specific applications, may also hamper commercialisation of nanotechnology. When there is a range of overlapping patents (as is the case for some types of quantum dots) then private investment may be inhibited because of a lack of clear ownership of the intellectual property[22]. Unnecessarily broad patents can also be a barrier to innovation in nanoscience, preventing other researchers or companies from developing new knowledge or applications[23]. Products involving nanotechnologies will also usually require a range of distinct technologies, so there is the potential for patent disputes (if broad patents have been filed) and/or the need for cross-licensing of patents.

Venture capitalists are realising that quick returns are unlikely from nanotechnologies, and that R&D that utilises manufactured nanomaterials in products or processes offers better potential returns than business plans that simply produce nanomaterials such as carbon nanotubes. There is also recognition that research aligned to clear market needs, and where marketing and distribution channels are already in place, provides safer investment opportunities than potentially revolutionary applications.[24]

A broader perspective also needs to be included in determining which applications are useful and desirable to society at large.

2.4.2 Societal challenges

As with other new technologies, some potential areas of nanoscience and nanotechnologies are generating concern about their broader societal impacts, such as:

- Uncertainty over environmental and human health risks associated with manufactured nanomaterials.
- Distribution of benefits from the technologies – will there be equitable distribution of benefits and costs across societies?
- Control of, and access to, the technologies – what is the potential for creating or exacerbating a "rich/poor" technology divide?
- Ethical implications. For example, the impacts of changes in manufacturing processes on workers and communities associated with existing manufacturing industries. How will the use of the technology affect privacy and informed consent?
- Perceptions of scientists and technologists "playing God" by manipulating matter.

The Center on Nanotechnology and Society, based at the Illinois Institute of Technology, maintains a database of documents related to ethical, legal and societal implications of nanotechnologies[25].

Many of these challenges apply to new and emerging technologies generally rather than reflecting specific nanotechnology issues. Nanotechnologies are, however, serving as a focal point for these challenges. Non-governmental and civil society organisations have produced reports outlining their perspectives on social and/or regulatory challenges associated with nanotechnologies[26].

Governments and other organisations have taken note of public concerns expressed over biotechnology issues. The desire now is to effectively address nanotechnology application concerns earlier in the R&D process by, for example, moving public engagement on nanotechnologies "upstream". It is hoped that this will result in nanoscale R&D and public policy being better informed about societal values and priorities. The key challenges are to avoid simply paying lip service to the issues, and public discussions of nanotechnology need to cover more that just safety issues[27].

22 Valigra L. (2005). "Nanotech: what makes investors bite". Science/Business. 8 December 2005. Available from http://bulletin.sciencebusiness.net/ (accessed 17 March 2006).

23 See "Nanoscience and nanotechnologies: opportunities and uncertainties". Royal Society and Royal Academy of Engineers. July 2004. Available from http://www.nanotec.org.uk/finalReport.htm

24 See Cientifica (2006). "VCs to nanotech: don't call us!" Available from http://www.cientifica.com. And also Osman T et al (2006). "The commercialization of nanomaterials: today and tomorrow". Journal of Metals 58 (4), 21- 24.

25 http://www.nano-and-society.org/NELSI/

26 See Arnall AH (2003). "Future Technologies, Today's Choices. Nanotechnology, Artificial Intelligence and Robotics; A technical, political and institutional map of emerging technologies." A report for the Greenpeace Environmental Trust (July 2003). Available from http://www.greenpeace.org.uk; "Down on the farm. The Impact of Nanoscale Technologies on Food and Agriculture." ETC Group (November 2004). "NanoGeoPolitics. ETC Group Surveys the Political Landscape" (July/August 2005), ETC Group Special Report - Communiqué No. 89. Both available from http://www.etcgroup.org.

27 See Wilsdon J, Wynne B, Stilgoe J. (2005). "The public value of science. Or how to ensure that science really matters". Demos. See http://www.demos.co.uk/catalogue/publicvalueofscience/

Lessons from societal responses to some biotechnologies may be relevant to nanotechnologies, but they cannot be uncritically applied[28]. Responses to biotechnologies were largely reactive, which is not desirable for nanotechnologies. Given that nanotechnologies are at an earlier stage of development than biotechnologies there are opportunities for public values to better inform research. However, given the pace of some nanoscale research, there is little room for complacency and there is often a tension between a desire to rapidly develop nanotechnologies and a commitment to undertake effective community engagement[29].

An important lesson from the debate about the use of genetic modification (GM) in agriculture is the need to consider the larger context rather than just the technology. For example, some of the concerns about GM crops often have more to do with the impacts and trends of current conventional farming practices as a whole rather than just gene technology.

Effective public engagement for science and technology is an ongoing exercise. Research and development is said to need a "reflexive capacity" that encourages more effective communication between interested parties and allows ongoing analysis and discussion to modulate directions and approaches to research and development[30]. Some advocate a cycle of targeted upstream and downstream engagement during the progress of research, from understanding the fundamental phenomena to developing commercial applications[31].

Some consider that there is a need for a more formalised approach to new technology assessments by involving a mixture of policy, research, industry and public perspectives, rather than having a narrowly focussed in-house technology assessment programme[32].

How effective are societal discussions for informing research and policy? This is an ongoing discussion. An illustration of how such upstream research can be effective is given by a study of public attitudes to forms of possum control undertaken by New Zealand's Parliamentary Commissioner for the Environment[33]. This study contributed to the research strategy focussing on inducing sterility in possums rather than on killing young possums or fetuses. Annex 4 examines some of the issues associated with integrating social and biophysical research in more detail.

In the UK and other European countries, a range of public engagement exercises have been undertaken. These include citizen juries, debates and discussions involving non-governmental organisations, policy makers, public representatives and scientists. The effectiveness of these exercises are still being considered. In the USA some universities are offering coursework, scholarships and/or outreach programmes to help provide fora (particularly for non-scientists) for information sharing and discussion about nanotechnologies. These are designed for people or groups who already have an interest in the subject rather than trying to inform the general public[34].

28 See Einsiedel EF, Goldenberg L (2004). "Dwarfing the social? Nanotechnology lessons from the biotechnology front." Bulletin of Science, Technology and Society 24(1), pp 28-33; Grove-White R, et al. (2004). "Bio to nano? Learning the lessons, interrogating the comparison". Available at http://www.demosgreenhouse.co.uk/archives/NANO_working_paper_jun04.pdf; and Sandler R, Kay WD (2006). "The GMO-Nanotech (Dis)Analogy?" Bulletin of Science, Technology & Society, 26 (1), pp 57-62.

29 Fisher E, Mahajan RL (2006). "Contradictory intent? US federal legislation on integrating societal concerns into nanotechnology research and development". Science and Public Policy, 33(1), pp 5-16.

30 Guston DH, Sarewitz D. (2002). "Real time technology assessment." Technology in Society 24(1-2), pp 93-109. Also viewable at http://cspo.org/products/articles/techassess.pdf

31 Jackson et al. (2005). "Strengths of public dialogue on science-related issues." Crit. Rev. Int. Soc. Pol. Philos. 8, 349-358.

32 Wilsdon J, Wynne B, Stilgoe J. (2005). "The public value of science. Or how to ensure that science really matters". Demos.

33 See "Caught in the headlights" Parliamentary Commissioner for the Environment. Available from http://pce.govt.nz.customer.onesquared.net/reports/allreports/0_908804_92_X.pdf

34 Toumey C & Baird D. (2006). "Building nanoliteracy in the university and beyond." Nature Biotechnology 24, 721-722.

2.4.3 Regulatory challenges

Safety issues are a key focus of government, research, and community discussions of nanotechnologies. There are many uncertainties about the potential adverse effects, exposure pathways and environmental fate of manufactured nanomaterials. Due to increased surface area and reactivity of smaller particles, the potential toxicity and other hazards[35] of manufactured nanoparticles often cannot be predicted from the behaviour of the same chemicals or compounds at larger scales of organisation. Manufactured nanomaterials do not necessarily present greater risks than some existing chemical production processes[36]. However, further research needs to be done to identify associated risks, to develop methodologies and instrumentation to detect and monitor nanoparticles, and to develop adequate exposure control strategies.

Some organisations have, consequently, called for a moratorium on commercial release of products containing manufactured nanomaterials until further research has established safety, and appropriate regulations are in place[37]. However, a survey of public perceptions of nanotechnology by the Woodrow Wilson International Center for Scholars[38] did not reveal strong public support for such a ban.

Research on occupational health and risks associated with manufactured nanomaterials is being conducted[39]. The UK Institute of Occupational Medicine, the US Environmental Protection Agency and the US National Nanotechnology Initiative have identified priorities for research to address potential human health and environmental hazards posed by manufactured nanomaterials[40]. There are concerns that development of new types of manufactured nanomaterials is proceeding at a much faster pace than investigations of toxicity, environmental mobility and persistence[41]. Some areas of application, such as cosmetics, are considered to currently be lightly regulated. The National Nanotechnology Initiative Fiscal Year 2007 Annual Report[42] signalled the need for greater US investment into research on toxicological and environmental effects of engineered nanomaterials.

The Australian Therapeutic Goods Administration surveyed the scientific literature on the safety of titanium dioxide and zinc oxide nanoparticles in sunscreens.[43] They concluded that if such nanoparticles remain on the skin surface or within the dead outer layer of the skin then they are likely to pose little risk. There may be risks if these nanoparticles penetrated viable skin cells, but additional research is necessary to determine if results from experiments on isolated cells are relevant to people.

Increasing attention is being paid to whether existing regulatory systems are adequate to deal with nanotechnology applications. There are a range of views on this (see, for example, the National Science Foundation report on responsible development[44]).

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35 Such as explosiveness, flammability, corrosiveness, and ability to oxidise.

36 Roubichaud CO, et al. (2005). "Relative risk analysis of several manufactured nanomaterials: an insurance industry context." Env. Sci. Technol. 39, 8985-8994.

37 See http://www.etcgroup.org and Friends of the Earth "Nanomaterials in sunscreens & cosmetics: small ingredients, big risks" (May 2006) available from http://nano.foe.org.au.

38 Macoubrie J. (2005). "Informed public perceptions of nanotechnology and trust in government." Project on emerging nanotechnologies at the Woodrow Wilson International Center for Scholars. Available from http://www.wilsoncenter.org; and Macoubrie J. (2006). "Nanotechnology: public concerns, reasoning and trust in government." Public Understanding of Science 15(2), 221-241.

39 See, for example, http://www.cdc.gov/niosh/topics/nanotech/, http://icon.rice.edu/research.cfm, http://cohesion.rice.edu/centersandinst/cben/research.cfm?doc_id=5008, http://faculty.smu.edu/eoberdor/nano%20page.htm, http://www.newscientist.com/article.ns?id=dn4825, http://es.epa.gov/ncer/events/news/2004/11_12_04_feature.html and http://www.nanotechproject.com/index.php?id=18.

40 See Tran L, et al. (2005). "Characterising the potential risks posed by engineered nanoparticles" http://www.defra.gov.uk/environment/nanotech/nrcg/pdf/nanoparticles-riskreport.pdf, http://www.epa.gov/osa/nanotech.htm and "Environmental, health, and safety research needs for engineered nanoscale materials" http://www.nano.gov/NNI_EHS_research_needs.pdf.

41 See the Royal Society and Royal Academy of Engineers nanoscience and nanotechnologies report available from http://www.nanotec.org.uk.

42 Available from http://www.nano.gov/.

43 "A review of the scientific literature on the safety of nanoparticulate titanium dioxide or zinc oxide in sunscreens." (January 2006). Therapeutic Goods Administration, Department of Health and Aging, Australian Government. Available from http://www.tga.gov.au.

44 http://www.nsf.gov/home/crssprgm/nano/dialog.htm.

The European Commission's Scientific Committee on Emerging and Newly Identified Health Risks[45] concluded that current regulatory methodologies require some modifications to deal with hazards associated with nanotechnologies and that there are gaps in knowledge, particularly with respect to toxicological and ecotoxicological methodologies. These findings are echoed in a draft report from the UK's Food Standards Agency, which also notes that there is some uncertainty over whether nanotechnology applications for food would be consistently picked up in regulatory assessments[46]. Developments of guidelines for workers health and safety, and for international agreement on nomenclature and measurement protocols are also of high importance[47]. However, Macoubrie notes that the public often have little trust in governments as risk managers, so there is a need to improve product testing before new products are sold[48].

Dupont USA and Environmental Defence, a non-governmental organisation, announced in June 2006 that they are working together to develop a "Framework for responsible nanotechnology standards". This is expected to cover the development, production, use and disposal of manufactured nanomaterials. The two organisations hope that other companies will follow their lead.

45 European Commission (2006). "Opinion on the appropriateness of existing methodologies to assess the potential risks associated with engineered and adventitious products of nanotechnologies" (SCENIHR/002/05). Modified opinion after public consultation, adopted by SCENIHR on 10 March 2006.

46 Draft Report of FSA Regulatory Review "A review of potential implications of nanotechnologies for regulations and risk assessment in relation to food." Food Standards Agency (March 2006).

47 International Risk Governance Council (2006). "Survey on nanotechnology governance. Volume B. The role of industry."

48 Macoubrie J. (2005). "Informed public perceptions of nanotechnology and trust in government." Project on emerging nanotechnologies at the Woodrow Wilson International Center for Scholars. Available from http://www.wilsoncenter.org.

3 New Zealand context

Section summary

- The MacDiarmid Institute for Advanced Materials and Nanotechnology, a Centre of Research Excellence, is the focus of nanoscience and nanotechnology R&D in New Zealand. Other research organisations are involved, to varying extents, in nanoscale R&D, and many are beginning to link up with the MacDiarmid Institute. The Faculty of Engineering at the University of Auckland is developing critical mass in a range of nano-related research projects. Greater synergy, and facilitation of better end-user linkages could be obtained by closer collaborations between the MacDiarmid Institute and the University of Auckland.
- Nearly all of New Zealand's R&D can be classed as basic research that is investigator-led. There is an emphasis on the synthesis and study of nanoscaled or nano-structured materials for industrial uses and the development of devices that incorporate nanoscaled structures or materials. We are developing particular research capability in nanoelectronics and conducting polymers. Capabilities in bio-nanotechnologies are beginning to develop. Spin-out nanotech companies are also forming.
- Knowledge and applications from many of the current nanoscience research programmes are more likely to be commercialised, if at all, by overseas companies rather than meeting local industry or other end-user needs.
- Current public investment in nanoscience and nanotechnologies is of the order of six to eleven million dollars per year. Most of this investment comes from the New Economy Research Fund.

3.1 Current nanoscience and nanotechnology capability in New Zealand

New Zealand has nanoscale research and development programmes in a range of areas which, for the purposes of the Roadmap, have been grouped into three areas (see Figure 2):

- tools and techniques;
- diagnostic devices; and
- creation of new materials.

The current focus is on developing reliable methods for creating and characterising nanoscaled structures and materials. This emphasis on understanding properties at the nanoscale mirrors the field in most countries.

In New Zealand research institutes are undertaking a diverse range of nanoscience and nanotechnology projects. Most of these consist of small teams of one or two researchers. Much of the research is university-based basic research, although many of the Crown Research Institutes have also initiated nanoscience projects (notably Industrial Research Limited (IRL), GNS Science, and Scion). Most of the research effort is associated with the development of new materials and electronic devices.

The MacDiarmid Institute for Advanced Materials and Nanotechnology has the most explicit focus on nanoscale R&D. It is a Centre of Research Excellence with funding managed by the Tertiary Education Commission. All five of the MacDiarmid Institute's research themes involve nanoscale research to some extent, and information on them is available on the Institute's website[49].

The MacDiarmid Institute (established in 2003) includes researchers based principally at Victoria University of Wellington, the University of Canterbury,

49 http://www.macdiarmid.ac.nz

Massey University, the University of Otago, and two Crown Research Institutes – IRL and GNS Science. The establishment of the MacDiarmid Institute enabled the purchase of significant pieces of analytical and fabrication equipment essential for nanoscience and nanotechnologies and this, along with the Institute's leadership, has helped to catalyse collaboration on nanoscience in New Zealand. The Institute's funding contributes to staff salaries and student fellowships as well as research programmes. Nanoscale R&D undertaken by organisations affiliated with the Institute can be funded from other sources (see Section 3.2).

A range of nanoscience projects are being undertaken by other research groups, as indicated in Figure 2. Many of these groups are now linking in, formally or informally, with the MacDiarmid Institute. A notable exception is the Faculty of Engineering at the University of Auckland which have only a few collaborations with the MacDiarmid Institute. Auckland's engineering faculty has a range of materials research centres that are developing strong capabilities in areas of nanoscience and nanotechnologies related to industrial applications, and they have strong links to national and international manufacturing firms. GNS Science, IRL, and Canesis also have significant pieces of research infrastructure that are important for the nanosciences.

Most of New Zealand's current nanoscale R&D activity is centred on basic research. However, some research groups have identified potential sectors where their nanoscience may be relevant. These groups include the University of Auckland (for industrial materials), HortResearch (sensors for fruit ripeness and human health and performance), Scion (wood products), the Nanomaterials Research Centre at Massey University (illuminated display companies and energy sectors), the Riddet Centre at Massey University (food and packaging) and Canesis Networks Limited (textiles and wool products). Nanoscale research being undertaken at the University of Auckland, Victoria University, the University of Canterbury and the University of Otago have potential medical applications.

A few spin-out companies from university research have appeared in recent years. These include:

- Nano Cluster Devices Ltd[50], developed out of research from the University of Canterbury, and which has established a joint venture with US-based NanoDynamics to market its self-assembling nanowires technology.
- PolyBatics Ltd[51] from Massey University which is seeking to develop a nanoparticle platform technology based on bacterial storage granules.
- Advanced Nano Imaging from the University of Canterbury, which is developing novel nanoscale imaging.

The Universities of Otago and Waikato are also in the process of spinning out companies based on nanoscale R&D. None of these spin-outs have strong links to existing New Zealand industries.

Nanoscale R&D in New Zealand is currently centred mainly on chemical, physical and engineering interests. Particular strengths and critical mass are developing in the areas of nanoelectronics and optoelectronics. Another area of strength that involves nanotechnology is advanced composite materials[52]. However, it is likely that businesses taking up this R&D will be based overseas.

A greater interest in biologically oriented projects is now emerging. These include development of biological imaging and sensing devices, the development of new materials for biological products, and potential food and packaging applications. For example, the Biopolymer Network (a joint venture between Canesis, Crop & Food Research and Scion) are examining the creation of new materials based on nano-structured biological products such as plant and wool fibres. Fonterra and the Riddet Centre are interested in applications in food production and

50 http://www.nanoclusterdevices.com/.

51 http://www.polybatics.com/.

52 Industrial Research Limited. "Nanotechnology commercialisation in New Zealand". A report to New Zealand Trade and Enterprise (June 2006).

packaging. A range of research teams are also looking at potential medical or human health applications, such as nano-enabled biosensors that provide greater sensitivity and better drug delivery mechanisms. The MacDiarmid Institute has established a bio-nanotechnology network[53] to facilitate coordination of bio-nanotechnology in New Zealand. Interestingly, New Zealand researchers appear to be authors of a relatively high proportion of published papers related to medical applications of nanoscience compared with other areas such as electronics[54]. This is surprising given the focus on materials and electronics in the current nano-related research (see Figure 2).

A few New Zealand businesses are taking an interest in the potential of nanotechnologies. These include Fonterra Cooperative Group, Fisher & Paykel, the plastics industry, Resene paints and the Wood Processors Association of New Zealand. Some of these have been supporting basic research. Organisations such as Canesis and the University of Auckland have good established links to potential end-users of nanotechnologies.

Currently social research in New Zealand associated with nanoscience and nanotechnologies is limited. The MacDiarmid Institute provided funding to the Agribusiness and Economics Research Unit (AERU) at Lincoln University to undertake a survey of public attitudes to nanotechnology[55]. This builds upon AERU's research into public attitudes to biotechnologies. Their first report on public attitudes to nanotechnology noted the need for a precautionary approach to development of the technologies, and the public desire for unbiased information. The report recommended that New Zealanders be included in the process to develop nanotechnologies, echoing a recommendation from the Bioethics Council in 2003.

Informal collaborations are developing between social scientists and nanotechnology researchers at the University of Canterbury. In addition, New Zealand has a range of research groups that have been investigating social issues and methods of engagement associated with science and technology related issues[56]. Capabilities and understanding gained from this research will be valuable in helping to inform future policy, research and societal engagement related to nanoscience and nanotechnologies but there is also a need for research that is specific to issues associated with nanoscience and nanotechnologies.

In early 2006 the MacDiarmid Institute developed a "Nanotechnology Initiative for New Zealand" which outlined where it would like to increase capability if more funding was available. This initiative identified six programmes for future nanoscience and nanotechnology research[57].
The programmes are:

- nanotechnologies for energy;
- bio-nanotechnologies;
- nanophotonics, nanoelectronics and nano-devices;
- nano- and micro-fluidics;
- nanomaterials for industry; and
- social impacts of nanotechnology.

These programmes are based on the MacDiarmid and other institutes' existing or desired capabilities. Based on the information in the Nanotechnology Initiative and a review of nano-related research activity in New Zealand[58] the two programmes "nanophotonics, nanoelectronics and nano-devices" and "nanomaterials for industry" have the greatest current research strength. As discussed later in sections 4 and 5, this Roadmap also considers New Zealand's economic advantages as well as existing capabilities in considering research directions.

53 http://www.bionano.net.nz/.

54 Sally Davenport, personal communication.

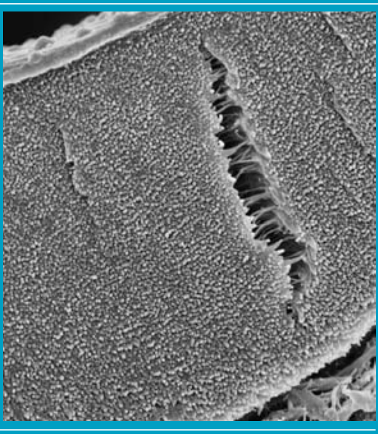
55 Cook AJ, Fairweather JR. (2005). "Nanotechnology - Ethical and Social Issues: Results from New Zealand focus groups." AERU Research Report 281. Available from http://www.lincoln.ac.nz/story9430.html.

56 See for example the Dialogue Fund Projects. Available at http://www.morst.govt.nz/current-work/science-in-society/dialogue/fund/; and other the MoRST report "Implementing the government's response to the Royal Commission on Genetic Modification's recommendations on research Priorities" (September 2003). Available at http://www.morst.govt.nz/current-work/biotechnology/research/RCGM-priorities/.

57 http://www.macdiarmid.ac.nz/ABOUT/initiative.html.

58 Industrial Research Limited. "Nanotechnology commercialisation in New Zealand". A report to New Zealand Trade and Enterprise (June 2006).

Making use of nature's nanostructures



A scanning electron micrograph image of a radiata pine fibre cell wall with cellulose macrofibrils. Each macrofibril is approximately 20 nm diameter. Magnification is 27,000x.

Cellulose is earth's most abundant polymer, with such stiffness it ranks as a high performance material. Research by Rotorua's Scion (formerly Forest Research) is seeking to exploit this property of cellulose on a nano scale, and is in the process of developing strong, light-weight, natural nano-fibre-reinforced composites. These composites are being investigated as alternatives to wood or synthetic composites such as fibreglass.

New Zealand currently exports a vast amount of our wood as unprocessed logs. However, Scion's nanostructure research could one day see this balance change and allow us to export more value-added commodities.

Dr Alan Fernyhough, head of Scion's Biomaterials Engineering, says the natural nano-fibre composites show the potential to have many advantages over wood or synthetic alternatives. "Basically, the finer the cellulosic fibre that we use as reinforcement, the greater the potential for achieving high performance – and for making more water resistant nanocomposites. If we can get the resin to penetrate the cell wall we can encase the individual wood fibrils in resin, protecting them from water.

"As composites the products will be mouldable, yet with higher strength and stiffness than wood. We have achieved some significantly higher stiffness ratings than radiata pine products by impregnating wood fibre cell walls with resin.

Dr Alan Fernyhough, Scion

"When such composites are compared to others such as glass fibre, the reinforcing fibres made from biologically sourced materials have lower density, so will often be lighter, and can be biodegradable."

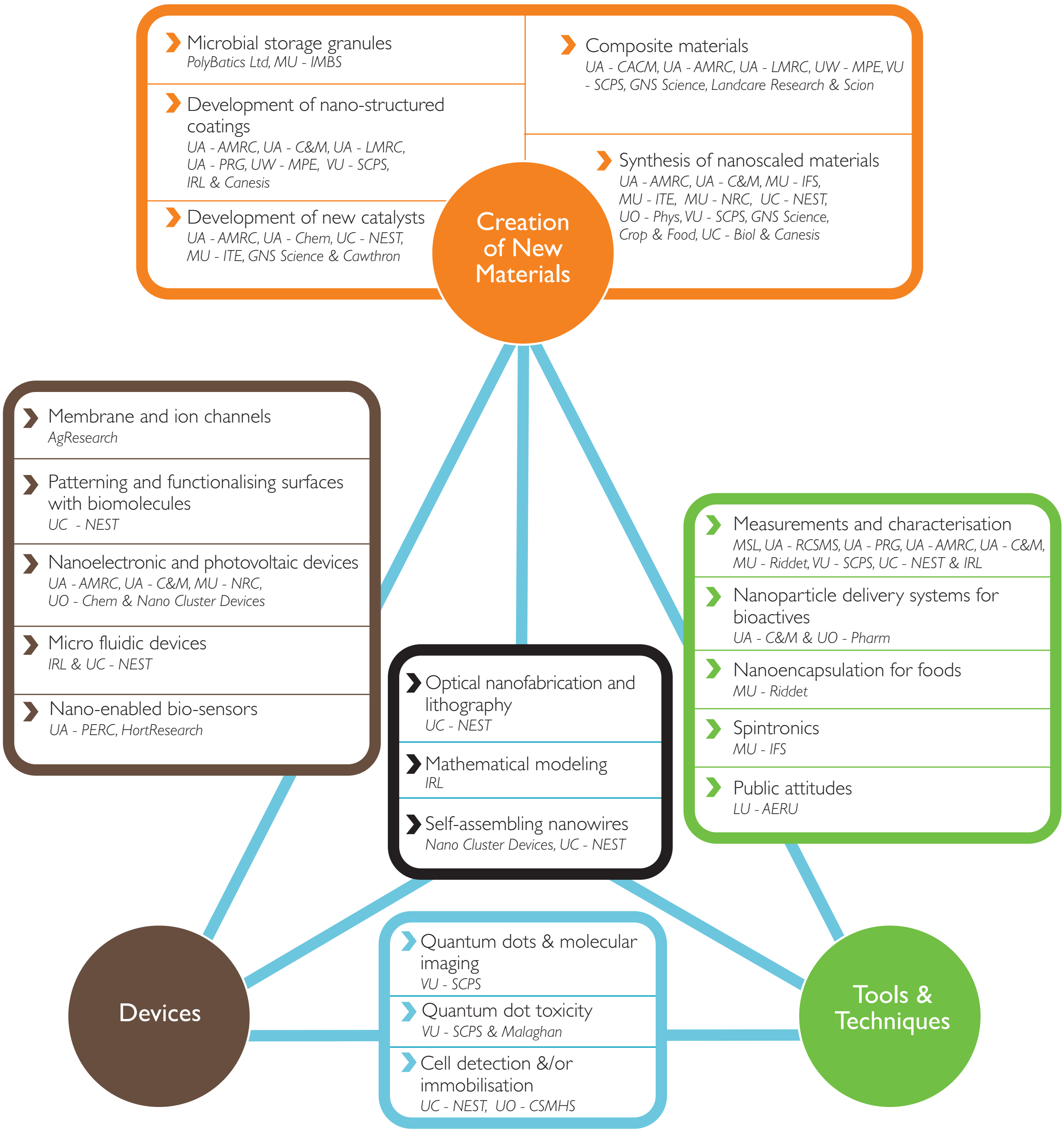
A scanning electron micrograph image of a fracture surface of a harakeke-epoxy composite. The finest filaments are individual macrofibrils torn from the fibres, and suggesting resin penetration into cell walls has occurred.

Further research is needed before such nanocomposites can become a commercial reality. However, when this is achieved the products are anticipated to be far superior to composites which are assembled from plant fibres on a macro-level.

Dr Fernyhough envisages great opportunities for the research. "Potentially more important applications will be outside of structural composites. If we can utilise these tiny fibrils and assemble them in a controlled manner, then functional nanofibrillar structures could be made with a huge range of potential applications including biomedical and pharmaceutical, bio-nano-reactors, and ICT, as well as structural engineering materials."

Figure 2

Current areas of nanoscience research and development in New Zealand and the organisations involved. The extent to which the research involves manipulation at the nanoscale varies. This diagram organises the types of R&D in relation to creation of new materials, development of tools and measurement standards, and the development of devices containing nanomaterials. The positioning of particular R&D gives an indication of which category or categories it falls into. For example, "optical nanofabrication and lithography" and "mathematical modelling" can contribute to all three categories. This diagram is not intended to be a rigorous categorisation and does not indicate the amount of resources associated with the different R&D projects.



KEY TO ORGANISATIONS

LU - AERU:	Lincoln University, Agribusiness & Economics Research Unit
MSL:	Measurements Standards Laboratory, Industrial Research Ltd
MU - IFS:	Massey University, Institute of Fundamental Sciences
MU - IMBS:	Institute of Molecular Biosciences
MU - ITE:	Institute of Technology & Engineering
MU - NRC:	Nanomaterials Research Centre
MU - Riddet:	Riddet Centre
UA - AMRC:	University of Auckland, Advanced Materials Research Centre
UA - CACM:	Centre for Advanced Composites Materials
UA - C&ME:	Chemical & Materials Engineering
UA - LMRC:	Light Materials Research Centre
UA - PERC:	Polymer Electronics Research Centre
UA - PRG:	Polymer Research Group
UA - RCSMS:	Research Centre for Surface and Materials Science
UC - Biol:	University of Canterbury, School of Biological Sciences
UC - NEST:	Nanostructure Engineering Science & Technology Group, Dept Electrical & Computer Engineering
UO - Chem:	University Otago, Dept of Chemistry
UO - CSMHS:	Christchurch School of Medicine & Health Sciences
UO - Pharm:	School of Pharmacy
UO - Phys:	Department of Physics
UW - MPE:	University of Waikato, Materials and Process Engineering
VU - SCPS:	Victoria University, School of Chemical & Physical Sciences

3.2 New Zealand investment in nanoscience and nanotechnologies

Nano-related RS&T is supported primarily by public funds. Using a broad definition of nanotechnology the estimated level of investment in 2005/2006 is approximately $11 million per annum (see Table 2). This level of investment is indicative only due to difficulty in assessing the proportion of R&D that is at the nanoscale. Additionally, some investments not readily identifiable as nanoscale research may have been missed or not included due to a lack of information. The figures exclude investment in capital expenditure and some funding schemes (such as CRI capability funds). The level of investment in research that meets the definition of nanotechnology given in Section 1 may be closer to $6 million[59]. It is difficult to directly compare investments in nanotechnologies between countries because of different definitions of nanotechnology and inconsistencies over inclusion or exclusion of salaries and infrastructure. Focusing solely on "nanotechnology" is also misleading because R&D at larger scales will be fundamental to the development of knowledge and applications from nanoscale research.

By comparison, public investment in biotechnologies in New Zealand is approximately $195 million per annum[60], and the environmental research output class of Vote RS&T was $86.4 million in 2005/2006.

Current key sources of funding for nanoscience and nanotechnologies are the Royal Society of New Zealand (via the Marsden Fund), FRST (in particular their New Economy Research Fund), and the Tertiary Education Commission ((TEC) through the Centres of Research Excellence scheme). The distribution of funding is shown in Table 2 and Figure 3. Several of the Crown Research Institutes are also using some of their Capability Fund allocations to develop nanotechnology capability, which is not covered in Table 2. The approximately $8 million of nanoscience funded by Vote RS&T makes up just over one percent of that Vote, which totals about $600 million per annum.

Some recently funded projects have not been included in the investments described above. These include a research project from Victoria University that received $1.2 million over three years in 2006 from the Government's International Investment Opportunities Fund to support development of silicon quantum dots for medical imaging. One and a half million dollars from the same scheme was also awarded to the University of Auckland for research on magnesium alloys, which involves some nanoscale research. In 2006 Nano Cluster Devices Ltd received $582,000 over three years from FRST for development of hydrogen sensors. A new Science and Technology Support Programme between New Zealand and France, called the Dumont d'Urville Programme, was started in 2006 to support collaborations in biotechnology and nanotechnology between the two countries. In the first funding round three nanotechnology projects were funded.

59 Paul Callaghan, personal communication.

60 This excludes investment via the Performance Based Research Fund.

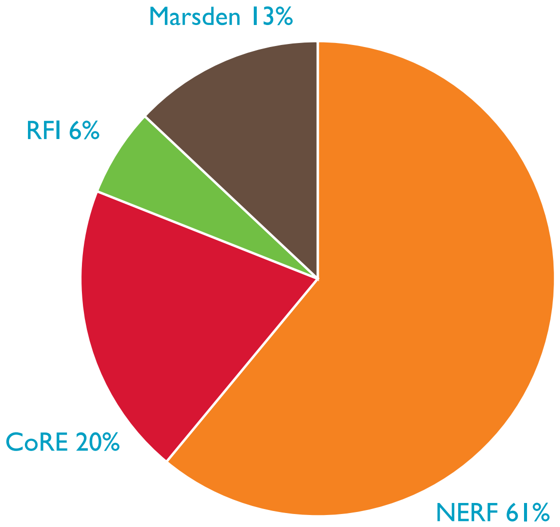
Table 2

Estimated New Zealand government investment in nanoscience and nanotechnologies. Note that these are indicative figures and represent investment in projects involving, to various degrees, nanoscale research or development, rather than investment specifically linked to nanoscale R&D. Other nanoscale research may also be receiving funding that is not identified here (for example, through Performance-Based Research Funds, CRI Capability Fund, FRST's Supporting Promising Individuals scheme, Health Research Council funding, university departmental grants, or private sector funding). Grants for capital expenditure are excluded.

Source of funding (and agency)	Fund's purpose	Number of nanotechnology-related contracts	Approximate maximum annual nanotech investment (2005 financial year)
Marsden Fund (Royal Society of New Zealand) - Vote RS&T	Basic research	7	$1.4 million
Centres of Research Excellence (TEC) - Vote Education	Encourage development of world class research	1	$2.2 million[a]
New Economy Research Fund (FRST) - Vote RS&T	Basic research targeted to potential applications	10	$6.8 million
Research For Industry (FRST) - Vote RS&T	Increase competitiveness of New Zealand industries and sectors	2	$0.6 million
Total		20	$11 million

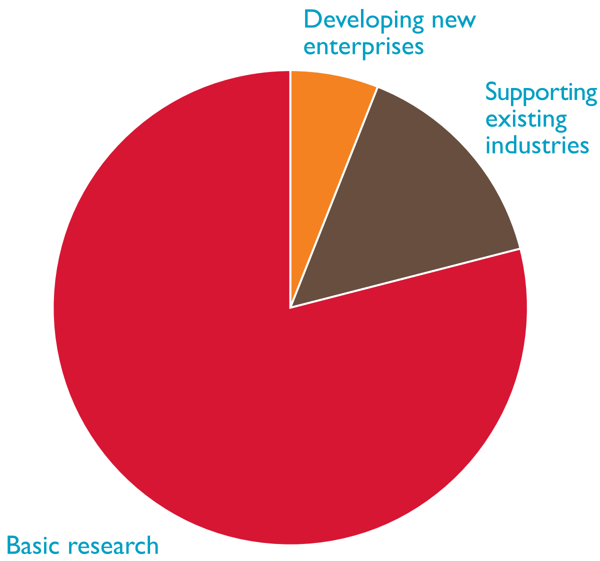
[a] This investment is assumed to be half of the annual funding for the MacDiarmid Institute for Advanced Materials and Nanotechnology, and excludes a one-off establishment capital expenditure grant of $9.8 million.

Figure 3



A. Indicative relative New Zealand public investment in nanosciences and nanotechnologies for 2005/2006. Percentages are based on data in Table 2. Marsden = Marsden Fund; CoRE = MacDiarmid Institute for Advanced Materials and Nanotechnology; RFI = Research for Industry; NERF = New Economy Research Fund.

B. Interpretation of investment from figure 3A in terms of basic and applied research. Applied research is divided into supporting existing industries and developing new enterprises, to reflect different funding schemes. Basic research includes investments from Marsden, CoRE and an assumption that 75% of NERF could be considered basic research. Supporting existing industries consists of RFI investment. Developing new enterprises has been allocated 25% of the NERF investment.



4 Relevant New Zealand government policy and strategy

Section summary

- RS&T is expected to contribute to achieving government policies, including its objectives for economic development, sustainable development and social policy. Economic transformation is a current Government focus that is particularly relevant to RS&T and to nanoscience and nanotechnologies.
- The biologically based industries are likely to remain as New Zealand's economic backbone and represent an important target sector for New Zealand's nanoscience and nanotechnologies.
- A range of industries are seeking to use science and technology to help increase productivity and/or product value. Many also want to improve their environmental sustainability.
- New Zealanders place high importance on quality of life and quality of natural environment.

4.1 Linkages to government policy and strategy

Aside from this Roadmap there is no existing government policy or strategy focussed on nanoscience or nanotechnologies. However, there is a range of more general policy statements and strategies that provide relevant context.

The government recognises that most New Zealanders want to have a highly productive and skilled society with sustainable economic growth that maintains or improves quality of life and does not degrade natural environments.

These objectives are expressed in the government's high level policies for economic development[61], sustainable development[62], and social development[63]. Current Government policy places emphasis on actions that will support:

- economic transformation;
- families – young and old; and
- national identity.

RS&T is expected to contribute to these objectives. They provide a clear context for the government's overall level of, and approach to, investment in science[64] including nanoscience and nanotechnologies.

A range of issue or sector specific strategies sit below these high level statements. These provide additional context for nanoscience and nanotechnologies although they give limited specific direction in this regard. They include the:

- Biodiversity Strategy;
- Biosecurity Strategy;
- National Energy Efficiency and Conservation Strategy;
- New Zealand Waste Strategy;
- Tertiary Education Strategy;
- New Zealand Transport Strategy; and
- New Zealand Trade and Enterprise sector engagement strategies[65].

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61 http://www.gif.med.govt.nz; see Growth and Innovation Framework.

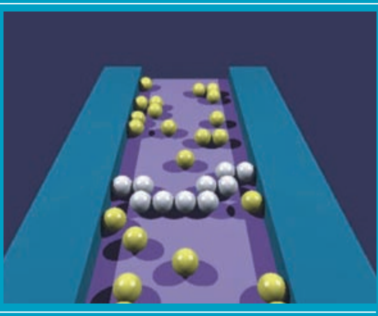
62 http://www.mfe.govt.nz; see Sustainable Development Programme of action.

63 http://www.msd.govt.nz; see Opportunity for All New Zealanders.

64 http://www.morst.govt.nz; see "Science for New Zealand: An Overview of the Science System 2006."

65 See http://www.nzte.govt.nz/.

New Zealand nanowires for a global market



A schematic of a chain of clusters.

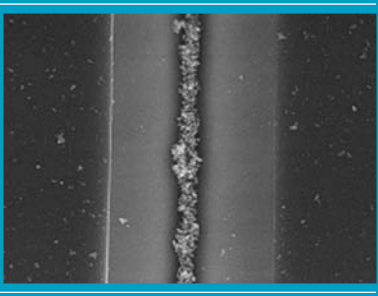
A New Zealand science team, from Nano Cluster Devices (NCD) Ltd in Canterbury, is on the forefront of research to produce self-assembling and self-connecting nanowires. Invisible to the naked-eye (and most microscopes) and as little as 10 nanometres (nm) wide (a human hair is approximately 80,000 nm wide) the minute wires have endless commercial applications ranging from chemical sensors to transistors.

NCD is New Zealand's first nanotechnology company. The team at NCD achieved a world-first with the development of a new technique involving atomic cluster deposition. The clusters, which are nanoscale particles containing a few hundred atoms, are directed into v-shaped trenches on a wave of inert gas. The clusters spontaneously weld together to form wires between pre-existing electrical contacts, which a current is immediately able to pass through.

Simon Brown.

NCD Director, Associate Professor Simon Brown, explains just how important these nanowires will become in the very near future. "We have developed and patented hydrogen sensor prototypes which may well be more sensitive than anything else on the market, but this is just the first of many applications. For example, there are a huge range of sensors which nanowires are ideal components for, because their combination of large surface area and high conductivity makes them very sensitive.

As well as electronics components other sensor devices the company is targeting include electromagnetic sensors, radiation sensors, magnetic field sensors, laser sensors, magnetic read heads, and sensors for biological molecules such as glucose, bacteria, viruses and chemical weapons. Glucose sensors in particular will be of huge benefit to the health industry, as the world's population lives to an older age where Type II diabetes is more likely to occur.



An electron microscope image shows a sub micron wire assembled in a silicon V-groove.

The technology has attracted world-wide attention, leading NCD to sign a license agreement with American Nanodynamics. Professor Brown notes that NCD developed from basic research, and that while revolutionary it is also easy to adapt to current manufacturing. "One of the reasons that we have achieved so much traction in the United States is that our processes are similar to, and obviously compatible with, processes currently used in the semiconductor industry."

4.2 New Zealand's economic base

Primary industries provide the backbone of the New Zealand economy and this is likely to remain the case over the coming decades. Exports from the primary sector (agriculture, horticulture, forestry, fishing, food and beverage, and manufactured products based on primary sector products) make up about 65% of total goods exports[66]. Primary industries contribute more than 10% of GDP[67], but in fact their influence on overall economic growth is much greater since other industries (such as manufacturing) are often reliant upon them. Given the size of the primary production sector, even small productivity gains translate into significant economic returns. For example, 3% per annum income growth in a $5 billion sector will add about $800 million over five years.

A report by MAF[68] notes that the major sources of agribusiness productivity growth are likely to include:

- dairy on-farm productivity and processing efficiency gains;
- increased sheep productivity (through biotechnology); and
- incremental productivity improvement in a range of sectors.

The report also notes that there will be an increasing international importance on standards, certification and verification related to agricultural products.

There is a moderate but growing economic contribution from a range of specialised manufacturing and information and communication technology companies[69]. New Zealand's specialised manufacturing sectors include automotive, aviation, defence, electronics, emerging technologies (such as high temperature superconductors), energy, environmental, heavy engineering, light engineering, marine and plastics[70]. However, these sectors service mainly small niche markets and so increased productivity in them will not have the same short and medium term impact as advances in the primary sector.

4.3 Sector strategies

In general, New Zealand industries are striving to achieve a range of the following:

- increase productivity;
- increase product value;
- respond to retailer and consumer demands (for example, for healthy, safe and affordable foods, new materials and designs);
- avoid or reduce adverse environmental and social impacts associated with primary production, manufacturing and associated activities;
- have an effective and efficient biosecurity system; and
- maintain or increase access to national and international markets.

Industries focus more on outcomes than the science or technology that may underpin these. Examples of how nanoscience and nanotechnologies could contribute to some of these strategic objectives are given in Table 3. Many of these may lead to incremental or "evolutionary" change (such as modest increases in productivity) rather than revolutionary developments. Depending on the industry and nature of the application incremental changes could still result in substantial economic or other benefits.

As in other countries, awareness of how nanoscience or nanotechnology can help address specific business problems or other issues is low in New Zealand. This is expected to change as nanotechnologies become better known and potential opportunities arising out of basic research are identified.

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66 http://www.stats.govt.nz/products-and-services/ext-trade-stats/default.htm.

67 Statistics New Zealand National Accounts Year ended March 2005 http://www2.stats.govt.nz/domino/external/pasfull/pasfull.nsf/7cf46ae26dcb6800cc256a62000a2248/4c2567ef00247c6acc2570c8006bff0c?OpenDocument.

68 Ministry of Agriculture and Forestry (2005). "Contribution of the Land-based Primary Industries to New Zealand's Economic Growth". Available at http://www.maf.govt.nz/mafnet/rural-nz/profitability-and-economics/contribution-of-land-based-industries-nz-economic-growth/index.htm.

69 See Statistics New Zealand external trade statistics - http://www.stats.govt.nz/products-and-services/ext-trade-stats/default.htm and the "Technology Investment Network Top 50 Technology Companies Report" (2005) - http://www.itinvestment.co.nz/modules.php?name=Content&pa=showpage&pid=45.

70 See http://www.nzte.govt.nz.

Watching paint dry

Dr Bridget Ingham, right, from IRL, working with Dr Mike Toney, from Stanford, at an X-ray diffraction (XRD) beamline at the Stanford Synchrotron Radiation Laboratory (SSRL) in the United States.

Dr Bridget Ingham of Industrial Research Ltd (IRL) says she has never found watching paint dry so exciting. Especially when watching it dry happens at the nanoscale using the Stanford Synchrotron Radiation Laboratory (SSRL) in the United States.

Dr Ingham's brief from New Zealand paint company Resene Paint Ltd was to observe the behaviour of various nano particles suspended in solution, and to track the changes of different paints as they dried.

"Paint usually begins drying on application, and the speed of drying is affected by humidity and air temperature. However, because the paint is opaque you can't see what is going on. But with synchrotron radiation we were able to examine the paint on a nano-scale to watch the process as it dries.

"We specifically examined structures that were 5 to 100 nanometres is size and how they behaved as the solvent they are suspended in evaporates. The synchrotron data we provided for Resene gave real-time information that could not be achieved any other way. Due to the encouraging results we have been allocated further beam time at Stanford to continue this work," says Dr Ingham.

Dr Graham Weir, Nanotechnology Platform Manager at IRL, says that while the use of nano particles, such as nano-scale pigments, in paint is not new the synchrotron observations are some of the first experiments of their type in the world. "An atomic-level understanding of the systems, sphere sizes and coalescence processes when paint dries will help Resene produce an even better quality of paint for various applications.

Possible applications of nanotechnology in paint in the future include UV resistance, anti-fungal and anti-bacterial coatings (for use in kitchens and bathrooms), fire retardant paints, anti-graffiti paints, self-healing paints, scratch resistant/tough paints, and 'smart' paints that respond to stimuli such as light.

Table 3

Examples of how nanoscience and nanotechnologies may be able to contribute to strategic objectives of existing industries.

Outcome	Potential contribution of nanoscience or nanotechnology	Potential benefits
Increased primary sector productivity	Use of nanoencapsulation to improve uptake of nutrients or pesticides. Highly sensitive, multifunctional nano-enabled sensors to rapidly detect and identify pests and diseases.	Likely to be of substantial national benefit through increased productivity. May contribute to improved environmental sustainability.
Increased manufacturing productivity	Nanostructured coatings that reduce maintenance requirements. For example, by reducing the amount of cleaning. Development of more effective nanostructured catalysts. Nano-enabled sensors that enable greater control of manufacturing process though the production cycle.	Niche applications that may meet local industry needs and/or service high value international markets. May result in development of a new manufacturing industry. May generate revenue via licensing agreements with overseas manufacturers.
Increased product value	Creation of higher value textiles or high performance composites through use of nanoscaled or nanostructured organic or inorganic materials.	Benefit will depend on nature of product and size of market.
Improved health and medical outcomes	New packaging materials or sensors that prolong shelf life or detect pathogens. New diagnostic and imaging devices that utilise functionalised nanoparticles. Smart drug delivery devices that more specifically target selected tissues or cells.	Improved food safety with national and international benefits. Niche medical applications targeted mainly to international markets. Likely to be commercialised by licensing to international pharmaceutical or medical companies.
Improved environmental sustainability	Reduction in waste products through more nanoscale processing systems. Reduction in use or production of hazardous materials through use of more effective or efficient nanoscaled components. Development of more efficient energy generation or transmission materials. Nano-enabled sensor webs that enable continuous monitoring of a range of environmental conditions.	Potentially national benefit through ameliorating adverse environmental and social effects of intensive industries, or more effective management of natural resources. May result in economic and/or non-economic benefits.

4.4 Societal values

The importance of environmental issues for New Zealanders is documented in a range of surveys. A report from the New Zealand Values Study, 2005[71] noted that most New Zealanders place high value on the environment, giving it priority over economic growth[72]. This reinforces the results of a survey by the Growth and Innovation Advisory Board[73] that identified quality of life and the quality of New Zealand's natural environment as core values for New Zealanders.

These and other surveys identify a strong desire to protect and restore natural habitats, to reduce waste and environmental impacts associated with human activities, and to have high standards of education and health services.

71 Conducted by the Centre for Social and Health Outcomes Research and Evaluation & Te Ropu Whariki.

72 http://www.shore.ac.nz/projects/Economic%20report%2021.06.05.pdf.

73 GIAB (2004). "Research on Growth & Innovation". Available from http://www.giab.govt.nz/work-programme/growth/index.html.

5 Directions for nanoscience and nanotechnologies

Previous sections identified international and national nanotechnology landscapes and New Zealand's economic and social goals. This section draws on the material in the previous three sections and presents the Government's perspective on the preferred future directions for nanoscience and nanotechnologies in New Zealand.

This section:

- affirms some existing directions and trends; and
- highlights areas where a change in current direction is warranted and where something new needs to be done.

Where possible this section also expresses directions as being relevant to a short time frame (to 2010), a medium time frame (2010 to 2015), or a longer time frame (beyond 2015).

Some issues, such as human resources in science and technology, are not specifically addressed by actions in this draft because they are currently being addressed by other policy initiatives from MoRST.

5.1 High level directions

This Roadmap provides a window into an area of science and application at a relatively early stage of development. There are currently no policy settings that are distinct to nanoscience and nanotechnologies, nor any overarching objectives for how New Zealand wants to manage nanoscience and nanotechnologies. For this reason, the Roadmap has necessarily been positioned at a high level and reaches some conclusions that relate more generally to New Zealand's overall policy for nanoscience and nanotechnologies, than the specifics of RS&T.

Nanoscience and nanotechnologies are developing rapidly internationally so it is difficult to reliably predict directions and outcomes. However, if these fields follow similar trends to biotechnology and ICT then aspects of nanoscience and nanotechnologies will become fundamental to many areas of science and technology.

In this sense this Roadmap indicates that:

Nanoscience and nanotechnologies are of growing importance to New Zealand.

Internationally, there is considerable investment in nano-related R&D, and it is expected that within five years applications will start to become common in globally traded products and processes across a wide range of sectors. Nanoscience is likely to be of considerable importance to improving knowledge and understanding of a broad range of materials, systems and processes and this, in turn, will contribute to innovations in many areas. Technological developments resulting from the knowledge and tools associated with nanoscience, and the convergence between other areas of science and technology such as biotechnology, ICT and advanced materials research are anticipated to influence a broad range of industries and sectors over coming decades.

Consequently, the Roadmap concludes that nanoscience and nanotechnologies will have an important role to play in supporting New Zealand's economic, environmental and social development. Identifying precisely how and when is difficult at this stage. The focus of the following directions is, therefore, on supporting and building capabilities so that New Zealand is well positioned to identify and develop opportunities and effectively manage challenges in this area. This is encapsulated in the following goal:

To enhance research, private sector, and government capabilities to absorb, develop and apply nanoscience and nanotechnologies for the benefit of New Zealand.

If New Zealand lacks people who understand nanoscience and nanotechnologies then as new knowledge, materials and devices become available we will be less able to benefit or otherwise respond to nanotechnology developments from around the world. A report from Treasury[74] noted the considerable extent to which agricultural productivity in New Zealand has been dependent on R&D from other countries and the importance of having capabilities (or absorptive capacity) in New Zealand to create opportunities from this. Such a situation will also apply to other sectors.

In some areas of nanotechnology New Zealand is likely to only maintain a watching brief on international developments. In other cases we are likely to need to be a fast adapter of technologies developed elsewhere to maintain competitiveness. While in others we will need to take a leading role due to our national needs and/or research capabilities.

In developing this Roadmap we have identified three main objectives for New Zealand's involvement with nanoscience and nanotechnologies. These are:

- Nanoscience and nanotechnologies should be developed and managed responsibly.
- Nanoscience and nanotechnologies should contribute to economic transformation through higher productivity, higher value products and diversifying the economy.
- Nanoscience and nanotechnologies should contribute to sustainable development and social well-being.

From these starting points we have identified a set of directions for nanoscience and nanotechnologies with particular relevance to RS&T. These are discussed in the following sections, along with immediate actions necessary for the next year to help establish and support these directions.

Government has agreed that the overall public RS&T investment should increase to the OECD average by 2010. This Roadmap identifies a range of needs and opportunities for nanoscience and nanotechnologies that will be considered in future RS&T investment strategies and signals areas of future investment focus.

Table 4 indicates the extent to which the directions in this Roadmap are existing or new and their level of priority for the next four and subsequent ten years.

74 Hall J, Scobie GM. (2006). "The Role of R&D in Productivity Growth: The Case of Agriculture in New Zealand: 1927 to 2001". New Zealand Treasury. Working Paper 06/01. Available at http://www.treasury.govt.nz/workingpapers/2006/twp06-01.pdf.

Table 4

Summary of Roadmap's statements of direction with respect to affirming existing RS&T directions and/or initiating new directions (shaded cells), and the priorities for these between now and 2010 and from 2010 to 2015.

	Affirms existing direction	Initiates new direction	Implementation Relevance to 2010	Implementation Relevance to 2015
Research			High	High
Research environment			High	High
Societal engagement			High	High
Uptake and commercialisation			Medium	High
Regulation			High	Medium

5.2 Research directions

Workshops and discussions with researchers lead us to conclude that significant research is required to still understand and control novel phenomena at the nanoscale before applications can be developed. Basic research[75] is the foundation upon which such developments occur. This research supports the development of skilled scientists, engineers and technologists who are alert to the ways in which science is developing and able to play a role as "knowledge bridges" to industry, communities, regulators and policy makers. Established research teams familiar with nanoscience and nanotechnologies will also provide the absorptive capacity to enable more effective responses to nanotechnologies entering New Zealand.

Nanoscience and nanotechnologies are a global research effort. Active participation in basic research is necessary to ensure that New Zealand is connected to global developments and is in a position to identify opportunities as they emerge internationally. The expertise of New Zealand's established nanoscience groups will help to both capture the opportunities and manage the challenges of nanoscience and nanotechnologies as they extend toward applications.

Basic research cannot proceed in a vacuum. "Science push" is not often an effective means for developing applications. To better inform basic research and to develop applied research[76] based on nanoscience and nanotechnologies researchers need to further develop relationships with industries and other potential end-users. Such relationships are necessary for recognising user needs and the potential relevance of nanoscience and nanotechnologies can be communicated.

New Zealand does not have the resources to support all proposals investigating nanoscience nor is able to compete effectively in all areas. We need to be strategic in our choices. As noted in Section 2.5, many other countries are focussing their efforts on existing competitive advantages and research strengths. This Roadmap identifies a medium term outcome for

75 Basic research as defined by the OECD Frascati Manual is "experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts, without any particular application or use in view."

76 Applied research as defined by the OECD Frascati Manual is "also original investigation undertaken in order to acquire new knowledge. It is, however, directed primarily towards a specific practical aim or objective."

application of nanoscale R&D to enhance existing competitive advantages while also identifying the need for longer term research and industry capability development to facilitate more transformative developments.

Research strengths

The MacDiarmid Institute's "Nanotechnology Initiative" (see Section 3.1) identified areas where New Zealand has existing research strengths or a need to more fully develop them. These strengths are associated with aspects of nanofabrication (such as lithography and self-assembly), modelling and development of new materials and coatings for industrial uses. A report commissioned by New Zealand Trade and Enterprise noted that critical mass in nanotechnology is developing in areas associated with nanoelectronics and conducting polymers.[77] These research strengths are not closely aligned with current areas of competitive advantages, and commercial opportunities from the research are more likely to be taken up by electronic and other manufacturing industries elsewhere.

If a research organisation or firm produces results that cannot be developed effectively within New Zealand, it is better to sell or license them to overseas firms than to leave the science or technology unused. This can still directly or indirectly benefit New Zealand through, for example, increased revenue for R&D and the ability to attract additional talented researchers. However, for publicly funded research a significant proportion of R&D should be aligned to national needs.

Research gaps

New Zealand particularly need to build research capacity in the interface between biotechnology and nanotechnology (bio-nanotechnology) and in social research associated with nanoscience and nanotechnologies. The former is required because of the importance of primary production to the economy and because of strong national support for good environmental management. Social research is required to help ensure priorities for nanoscience and nanotechnology are aligned with societal expectations (see Annex 4). This type of research cannot be done elsewhere since it is New Zealand-specific. Directions associated with societal engagement are considered in more detail in Section 5.4.

The MacDiarmid Institute sponsored bio-nanotechnology network[78] is facilitating interactions between biological, physical and chemical researchers and this initiative needs to be supported by development and funding of research projects that build critical bio-nano capability. Nanoscience, nanotechnologies and other fields of physical sciences and information technologies provide additional opportunities to capitalise on our biological production systems[79]. Such collaborative projects would also enable nanotech researchers to access more of the FRST and HRC research investment portfolios. Actions to facilitate such collaborative research are identified in Section 5.3.

Building capability in biological and social research related to nanotechnology does not signal that New Zealand's established areas of nanoscience and nanotechnologies do not need further support. On the contrary, it is from these established groups that New Zealand's broader nanoscience and nanotechnology capabilities will grow. These established research teams will also provide the absorptive capacity that will enable us to more effectively respond to nanotechnologies that will enter New Zealand from elsewhere.

National benefit

Ideally strong science and technology capabilities should make substantial contributions to national benefit[80]. In some cases, capabilities will be necessary to address issues of national need or benefit, as

77 Industrial Research Limited "Nanotechnology commercialisation in New Zealand". A report to New Zealand Trade and Enterprise (June 2006). Note that this report uses a broader definition of nanotechnology that the one used in this Roadmap.

78 See http://www.bionano.net.nz/php/home.php.

79 See the report "Outcome Evaluation of the New Economy Research Fund". Abt Associates (2006). Available from http://www.morst.govt.nz/publications/evaluations/nerf/.

80 National benefit, or benefit to New Zealand, comprises the total economic, social and environmental benefits that accrue to New Zealand residents from the creation and application of new knowledge generated by RS&T. Source: "Benefit to New Zealand' Principles for publicly funded RS&T." MoRST – http://www.morst.govt.nz/publications/a-z/pace-resources/benefit-to-new-zealand/.

indicated by developing bio-nanotechnology and social research capabilities. In other situations, a new application or industry of significant national benefit could be developed from existing strong science and/or technology capability.

While the potential for nanotechnologies to create new industries is frequently highlighted, nanotechnologies are more likely in the medium term (10 to 15 years) to make greater contributions to existing industries. These contributions are also more likely in the medium term to provide incremental or evolutionary rather than revolutionary changes. This assessment is supported by surveys from nanotechnology advisory firms such as Lux Research and Cientifica, the National Center for Materials Science in the USA, and from the national strategies noted in Annex 2.

Of New Zealand's existing industries, primary production is the most significant. Consequently, nanoscience and nanotechnologies that contribute to substantive improvements in productivity, product value and environmental sustainability in this sector (and associated industries such as the food and beverage and wood processing sectors) are likely to have the greatest national benefit, at least in the medium term. Such potential applications are expected to develop out of increased basic research collaborations with biological researchers and industry interactions that were noted above.

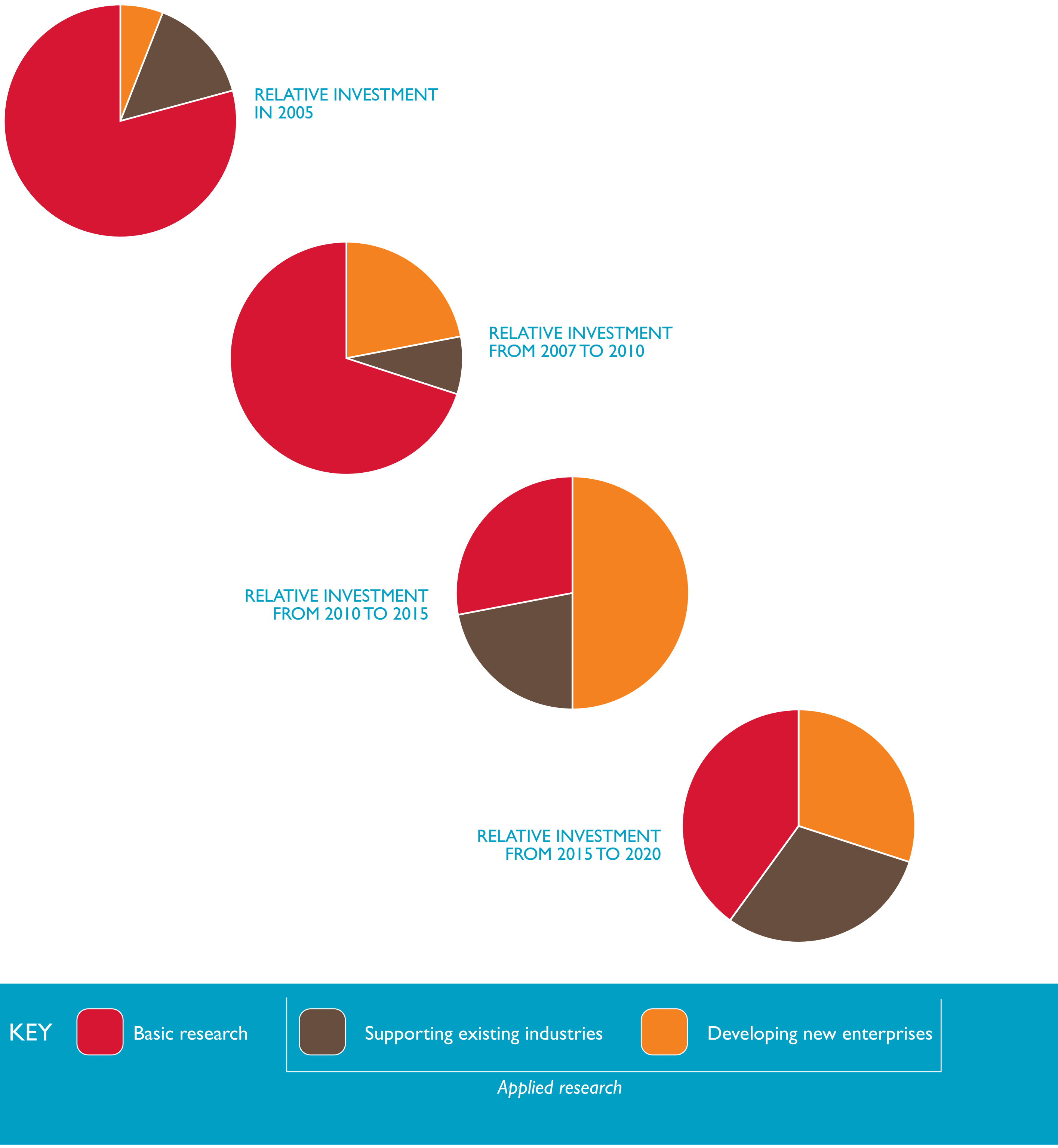
It is not necessarily clear at this stage how, and whether, nanoscience and nanotechnologies will contribute to addressing particular industry needs. This could, in part, be answered by researchers discussing with industries the opportunities that nanoscience and nanotechnologies raise. Indications of potential applications can be seen in Table 3 (Section 4.3) and in sector reports (Annex 3).

Research that leads to the development of new production systems may be more likely to provide revolutionary opportunities for establishing new comparative advantages. Outcomes from these areas of research are viewed as riskier and longer term because of the additional challenges posed by developing and establishing new industries (see Section 2.5). To keep New Zealand's opportunities open for longer term beneficial applications of nanoscience and nanotechnologies, continued support is required for capability building in interdisciplinary science and engineering that is particularly focussed on truly novel properties that emerge at the nanoscale. Given that there is still much to understand about nanoscale properties, a focus on scientific excellence will most likely be the successful long term strategy.

The evolving focus on basic and applied areas of research associated with nanoscience and nanotechnologies is shown in Figure 4. It is important to emphasise that over the coming years nano-related R&D is expected to permeate a range of fields. As with biotechnology now, nanoscience and nanotechnologies will be parts of broader research projects, so that there will be an increasing number of FRST and HRC output classes and investment portfolios supporting nanoscale research.

Figure 4

Indicative evolution of relative New Zealand investment distribution over time in nanoscience and nanotechnologies. The investment is divided into basic research and applied research linked to either supporting existing industries (for example, Research for industry [FRST] and Technology for Business Growth [Tech NZ] schemes) or developing new enterprises (for example, New Economy Research Fund (NERF) [FRST]). Note that some funds, such as NERF and HRC research contracts, will cover a spectrum of basic and applied research. Note also that this figure is intended to show how the distribution of investment should evolve. It does not imply that there will be no change in levels of overall investment. For the purpose of this illustration it is assumed that for the 2005 investment 75% of NERF can be considered basic research, with the remainder linked to developing new enterprises.



Statements of direction: research

Direction 1

Until 2010 the main focus for investment in nanoscience and nanotechnologies should remain on basic research that builds capability and critical mass.

This research should contribute to the understanding and exploitation of novel properties that emerge at micro- and nanoscales and enable New Zealand science to keep in touch with international developments and to identify emerging research and application opportunities.

Direction 2

Additional investment in the medium term (to 2015) should be targeted to research that shows strong relevance and benefit to existing industries.

Particular consideration should be given to applications in our biologically-based industries.

Direction 3

In the longer term a greater proportion of investment should be targeted to supporting research and development that have more transformative application potential.

Subsequent directions underpin the Directions 1, 2 and 3.

Direction 4

Greater emphasis should be placed on building capability in bio-nanotechnologies.

Direction 5

The needs of New Zealand's existing industries should inform research in nanoscience and nanotechnologies.

Further directions are listed in subsequent sections.

Immediate actions (2007):

- Minister of RS&T to instruct FRST and HRC to take account of these directions in their future investment decisions.
- Minister of RS&T to ensure that other agencies with interests in RS&T investments in nanoscience and nanotechnologies (Department of Labour, Environment Risk Management Authority, Ministry of Agriculture & Forestry, Ministry of Economic Development, Ministry of Education, Ministry for the Environment, Ministry of Health, New Zealand Food Safety Authority, New Zealand Trade and Enterprise and Tertiary Education Commission) are informed of these directions for research and work toward a coherent whole-of-government investment in nanoscience.

5.3 Research environment

Section 5.2 identified research directions. This section outlines organisational directions and actions that are needed to support that research.

Collaboration

New Zealand's nanoscience is largely unfocussed with many small research teams. For an emerging area of science this is to be expected. Opportunities for application of nanoscience and nanotechnologies will often be serendipitous. It is desirable to create the right environment for such discoveries to appear and to be further developed. This will come partly from encouraging greater collaboration, interdisciplinary research and young researchers to work in the area.

Greater collaboration of New Zealand's nanoscience and nanotechnology capabilities will help build critical mass and avoid duplication. The MacDiarmid Institute is taking a leading role in this, particularly with respect to some of the basic research. However, closer collaboration between the Institute and the University of Auckland would be desirable. Collaborations both within New Zealand and with research teams elsewhere are necessary. This would facilitate greater sharing of infrastructure, building of interdisciplinary teams and development of stronger links between basic and more applied research.

Infrastructure

A key feature of nanoscience is the dependence on appropriate tools and methodologies to characterise features and properties at the nanoscale. International initiatives are underway to develop common standards and methodologies associated with nanoscience and nanotechnologies, and to facilitate access to infrastructure. Researchers that MoRST has talked to consider that having time- and cost-effective access to key infrastructure is a key issue for maintaining high quality research and competitiveness in nanoscience. Infrastructure and technical expertise to support nanoscience and nanotechnologies can be expensive and requires ongoing maintenance and upgrading, or training. The existing facilities are unlikely to be adequate to cope with demand in the medium term. Universities and research organisations will, therefore, need to pay attention to capital investments that support their nanoscience research strategies.

Coordinating and facilitating access to existing infrastructure is essential to avoid unnecessarily duplicating equipment and resources. Consortia, national centres or other ways of facilitating access to large infrastructure for nanoscience and nanotechnologies have been, or are being, established in other countries. The MacDiarmid Institute and the various materials research centres at the University of Auckland are the natural foci around which such infrastructure coordination can further develop. There are also opportunities for the New Zealand government and researchers to improve access to key infrastructure in countries and regions such as Australia, Asia, Europe and the USA.

Access to infrastructure is not an issue unique to nanoscience and nanotechnologies and is being addressed through initiatives such as the Research Infrastructure Advisory Group[81] and the more explicit support for "backbone" science through current proposals to introduce more stability into the research funding system. There are also government-funded schemes that can facilitate development of international linkages, such as the International Investment Opportunity Fund, and the International Science and Technology linkages fund.

Another of the issues raised by researchers has been the critical need for prototypes to demonstrate to potential customers. Capabilities for these are often not found in research laboratories, so collaboration with the private sector to enable transition from proof-of-concept to prototypes is necessary. Some existing schemes provide mechanisms for supporting such linkages. For example, the Partnerships for Excellence framework run by the Tertiary Education Commission and the Research Consortia investments managed by FRST.

81 See MoRST's website http://www.morst.govt.nz.

New Zealand appears to have adequate schemes in place to facilitate access to infrastructure associated with nanoscience. However, research organisations, funding and investing agencies, and policy makers will need to remain alert to nanoscience and nanotechnology developments to effectively support access to key infrastructure.

Skills and talent

As in other areas of science and technology, the fields of nanoscience and nanotechnologies are becoming increasingly interdisciplinary. Advances in the understanding of phenomena at the nanoscale, and development of applications based on these phenomena, require the collaboration of engineers and scientists from a range of disciplines. Such interdisciplinary research is also important for societal engagement (section 5.4), effective uptake and commercialisation (section 5.5) and developing risk assessment and regulatory capabilities (section 5.6). As discussed in section 2.4.1, there are organisational, funding, and cultural challenges in establishing interdisciplinary research teams. Interdisciplinary research can be facilitated through access to critical infrastructure, along with funding and management structures that support and encourage collaboration centred on this.

Establishing effective interdisciplinary research teams requires a range of factors and takes time. Funding and investment agents and research organisations have roles to play in encouraging such teams to develop and supporting them over the long term. Centres of Research Excellence, Research Consortia and the Partnerships for Excellence scheme provide examples of coordinating resources and infrastructure. The MacDiarmid Institute, through the involvement of both universities and CRIs, provides a good organisational model for supporting interdisciplinary nanoscience and nanotechnologies. Universities and other research organisations will also need to use the capability funds they control to support and develop interdisciplinary teams.

As with other areas of science the development of nanoscience and nanotechnologies will require increasing numbers of appropriately educated and skilled people. Nanoscience and nanotechnologies, however, may pose particular challenges because they are currently being developed by young researchers and there is the need to encourage development of interdisciplinary teams that encompass a broader suite of skills.

While scientists and engineers can be sourced from overseas this does not replace the need for New Zealand to support its own science skills or to develop an interdisciplinary science culture. The rapid growth of nanoscience internationally may also mean that suitably qualified scientists, engineers and technicians become harder to recruit. However, the increasing profile of nanotechnologies may attract sufficient new entrants into the science system so that recruitment issues become less significant. The Government and the Institution of Professional Engineers New Zealand are promoting engineering and technology careers through the "Future in Tech" scheme[82].

There is also a need to ensure that the disciplines central to nanoscience and nanotechnologies, namely physics, chemistry, biology, mathematics, engineering and design, continue to attract top students. Ensuring students have access to classroom resources that reflect contemporary research will provide them with the ability to make informed choices about future options and opportunities. In addition, recent research[83] has shown a wide range of drivers are involved in student decisions to continue with sciences. Secondary and tertiary institutions and education policy agencies need to recognise these factors and develop teaching programmes that encourage ongoing student participation in the sciences.

Tertiary education organisations will also need to evaluate the types of courses and structures they need to offer to produce graduates with knowledge and skills that will be required for nanoscience and nanotechnologies. A greater emphasis on training

82 See http://www.futureintech.org.nz/.

83 Hipkins R, et al. (2006). "Staying in science 2. Transition to tertiary study from the perspectives of New Zealand Year 13 science students". New Zealand Council for Educational Research. Available from http://www.nzcer.org.nz/pdfs/14605.pdf.

undergraduates and graduates in interdisciplinary research will have long term beneficial consequences.

New Zealand policy, teaching and research organisations and industries will need to work together to develop incentives and support for developing, attracting and retaining suitably skilled people that can contribute to nanosciences and nanotechnologies.

International standards

An additional important factor needed to support research and development is having clear and consistent national and international standards. Establishing agreed methods, standards and guidelines for characterising materials at the nanoscale is becoming an active area of international discussion. It is likely that the Codex Alimentarius Commission[84] will become involved as nanotechnology is used in food preparation, packaging and processing. Such standards are likely to have regulatory and trade implications as well, so it is important for New Zealand, and jointly with Australia where the standards are relevant to the Australia New Zealand Food Standards Code, to actively participate in such forums.

There are roles for both research organisations and government. The Measurement Standards Laboratory, based in Industrial Research Limited, is New Zealand's national metrology institute, responsible for the provision of physical measurement standards in New Zealand. It will have an important role in providing information and advice relating to measurement standards associated with nanotechnologies, and the provision of standards of measurement. Other research organisations also have measurement capabilities for nanomaterials and may need to participate in some standard setting discussions.

84 http://www.codexalimentarius.net/web/index_en.jsp.

Statement of direction: research environment

- Direction 6

  The government will work to ensure the appropriate tools and skills are available to underpin the research directions.

  There will be a focus on greater research collaboration, improved access to equipment, support for interdisciplinary research and skills development, and active involvement in setting international standards.

Immediate actions (2007):

- MoRST to support a delegation from the Australian Nuclear Science and Technology Organisation and Nanostructural Analysis Network Organisation in Australia to visit New Zealand organisations to discuss access by researchers in both countries to key research equipment associated with nanoscience and nanotechnologies.
- MoRST and the research sector to support the development of resources for school students in science and mathematics to provide contemporary learning experiences in these areas.
- TEC to undertake a case study that will identify the nanoscience sector's educational needs for contributing to economic transformation.
- Universities and Crown Research Institutes to consider how to effectively support and maintain interdisciplinary research teams and the need for training graduates in these areas.
- Government to maintain an active involvement in international standard setting discussions associated with nanoscience and nanotechnologies.

5.4 Societal engagement

There is a desire, internationally, to ensure that government-sponsored R&D associated with nanotechnologies is managed "responsibly", so that societal expectations and values are taken into account during technology development. New Zealand has social research and public engagement capabilities that present opportunities for us to take an international leadership role in this area.

It is important to note the distinction between social research and public engagement. The former is concerned, among other things, with developing an understanding of the values and perceptions of individuals and communities. It provides knowledge and methodologies that can be used by policy makers and researchers to help understand societal attitudes towards particular areas of science and technology. Public engagement has evolved from policy and research organisations simply promoting science and technology and raising awareness, to being more proactive in having deeper public discussions about science and technology and their roles in society.

Social research contributes to informing research and policy associated with nanoscience and nanotechnologies by providing a richer understanding of the social context that decision making needs to sit within. It can identify what knowledge and technologies are wanted and perceived as beneficial by wider society. As noted in section 4.3, research has identified some general societal values. These public values and perceptions are yet to be tested with respect to specific areas of nanoscience and nanotechnologies. The research also needs to broaden beyond surveys of public attitudes.

Social scientists, nanoscience researchers and policy makers would benefit from working together on selected projects to develop a shared understanding of the issues and approaches each is concerned with and to work together to ensure that the people involved in nanoscience and nanotechnologies are informed by societal expectations. This applies not only to R&D undertaken in New Zealand but also to science and technologies that may come to New Zealand, as medical treatments, agricultural biotechnologies and information technologies already illustrate. How and when to do this can be challenging. An important preliminary step is to get biophysical and social scientists, as well as policy makers, understanding each others cultures and methods (see Annex 4).

The Bioethics Council is an agency with a particular focus on enhancing cultural, ethical and spiritual aspects of biotechnology and for ensuring that those involved in the application of biotechnologies take account of New Zealanders' values. The Council sets its own work programme so it cannot be directed to undertake work on nanoscience and nanotechnologies. Additionally, it should not be the only organisation involved in such areas.

Non-scientists recognise the importance that science has to New Zealand and when it comes to science and technology issues they want to hear from the scientists[85]. Scientists need to talk about their science and explain its connections with daily life. While many scientists are willing to engage with the public about their research, they can be restricted by time and resources. Similarly, many people in the community would like to discuss science and technology but may be inhibited by perceived lack of knowledge and/or lack of opportunities to take part in such discussions. These discussions will be most constructive when specific research and applications are discussed rather than discussing nanotechnologies in general. Research organisations need to support researchers undertaking public engagement activities associated with nanoscience and nanotechnologies. Funding and investment agencies also need to recognise the importance of scientists' public engagement activities.

Nanoscience and nanotechnologies present a broad range of potential opportunities and challenges. The pace of the research is proceeding rapidly. It is essential that government agencies remain well informed of national and international developments and of societal views and expectations. Coordination of policy across government will be required so that policy settings are consistent and recognise both the opportunities and challenges.

85 See "Science and the general public in 2005", available at http://www.morst.govt.nz/publications/a-z/science-and-the-general-public-in-2005/.

Statements of direction: societal engagement

- Direction 7

  Social research should inform New Zealand's nano-related research and policy.

- Direction 8

  The Government will support inclusive forms of public engagement that enable communities to contribute to decisions on nanoscience and nanotechnology application.

Immediate actions (2007):

- Research funding and investment agents to support both:
  - social research that informs the nanoscience research and policy communities on the public values and priorities for science and technology, including integration of social and nanoscience research in joint programmes; and
  - research that investigates effective means for the public to engage with science and technology issues.
- Research organisations to recognise and support researchers' public engagement activities.
- MoRST to convene a workshop at the MacDiarmid Institute AMN-3 conference in February 2007 for nanotech researchers, social scientists, policy makers and other interested groups to identify particular research questions and approaches that facilitate responsible development of nanoscience and nanotechnologies.
- MoRST to coordinate ongoing discussions across government on policy issues associated with national and international developments in nanoscience and nanotechnologies.

5.5 Uptake and commercialisation

Section 5.2 signalled the need to develop stronger linkages between researchers, who will understand the technical challenges and opportunities, and end-users who understand national or global market needs and opportunities. As noted in section 2.4.1 some countries are better at commercialising their science and technology than others. This is not a nanotech-specific issue, and much of the discussion and actions listed below relate to uptake and commercialisation of science and technology in general. CRIs and universities have established linkages with local and international private sector groups or firms that are good in some areas, such as the primary sector, and patchy in others, such as the manufacturing sector.

These interactions can make R&D more relevant to New Zealand's needs. A range of outcomes may result from these linkages, such as transfer of knowledge and know-how, licensing arrangements, joint ventures, or investment in new companies. The nature and effectiveness of R&D linkages will depend on the nature of the research, type of industry, funding arrangements and interest of end-users.

New Zealand already faces challenges with some firms not recognising the contribution that R&D can make to their business. The newness and revolutionary nature of some nanoscience and nanotechnologies, combined with the often small and diverse nature of New Zealand's manufacturing sector, are likely to make developing such research-industry linkages particularly difficult. Universities, CRIs and other research organisations all have roles to play in linking their research to industry needs.

New Zealand already has a range of funding schemes to facilitate commercialisation of research. These include the Pre-Seed Accelerator Fund, the Seed Co-investment Fund, the New Zealand Venture Investment Fund and the funds provided by Technology New Zealand. These currently appear fit-for-purpose for nanotechnologies. However, as discussed in Section 2.4.1, more revolutionary technological applications could present challenges due to the scale of funding required, the possibly long time frames needed to create new products or processes, the need for compensatory changes in other parts of the production process, and an absence of existing marketing or distribution channels systems.

It does not appear that commercialisation of nanoscience and nanotechnologies present challenges that require additional policy support beyond existing initiatives. Consequently, no directions for uptake and commercialisation are specified in this Roadmap, beyond the need to better link researchers with potential users of the technologies (see Section 5.2). As with public engagement (Section 5.4) it is important for research organisations to recognise and support staff that develop industry links. With few commercial applications, there are few immediate actions that can be undertaken to assist commercialisation of nanotechnologies. MoRST and New Zealand Trade and Enterprise are, however, maintaining an active interest in commercialisation issues raised by nanoscience and nanotechnologies.

Immediate actions (2007):

- Research organisations to further develop linkages with relevant industries or user groups and support researchers engaging with industries to highlight opportunities associated with nanoscience and nanotechnologies.
- MoRST to continue developing policies that create stronger research partnerships between the public and private sector and increase private sector investment in R&D.

5.6 Regulation

Safety issues are a significant focus of government, research, and community discussions of nanotechnologies. A variety of reports have noted that additional research and the review of existing regulatory regimes is required to reduce uncertainty. A range of products currently in New Zealand are likely to contain manufactured nanomaterials. These include some fuel additives and skin care products. However, since labelling of such materials is not mandatory, a complete list is not available.

Current regulation

In New Zealand most current research involving manufactured nanomaterials will be small scale laboratory research. While exempt from gaining a Part V approval under the Hazardous Substances and New Organisms (HSNO) Act such small-scale laboratory research is not exempt from regulation and must be conducted in accordance with the Hazardous Substances (Exempt Laboratories) Regulations 2001. These Regulations prescribe requirements for laboratory design, recording hazardous substances, handling and storage of hazardous substances, personnel and emergency response plan requirements.

New Zealand's HSNO Act triggers risk assessment for substances based on hazard thresholds[86]. In comparison to other regulatory systems this process can enable a greater consideration of the potential risks presented by manufactured nanomaterials, which may be manufactured in gram rather than tonne quantities. A challenge, however, is to ensure that manufactured nanomaterials are identified for the regulatory process because the hazardous properties of the nano forms of these materials may be different from their larger forms.

For example, the Environment Risk Management Authority, which implements the HSNO Act, has issued a Group Standard on cosmetics that provides guidance relating to cosmetics containing nanoparticles. If the cosmetic falls within the scope of the Group Standard, the importer or manufacturer of a cosmetic product that contains nanoparticles (other than zinc oxide or titanium dioxide) that are intentionally added must inform the Authority of the nature of the nanoparticles the first time they import or manufacture the cosmetic. This will help inform regulators and others of cosmetics in New Zealand that contain manufactured nanomaterials and provide a basis for any future action if required.

Researchers and others will also have to comply with health and safety guidelines established by their organisations and required under the Health and Safety in Employment (HSE) Act. The HSE Act is sufficiently general in its definition of a "hazard" that it would be applicable to any substance that has health consequences. The HSE Act provides a general duty on all employers to provide a safe place of work, and sets in place a hazard identification and management system that requires anything that could be hazardous to workers to be systematically identified and assessed to determine whether or not it is a significant hazard. If the hazard is found to be significant, the employer must take steps to eliminate, isolate or minimise the hazard.

There are also monitoring provisions under the HSE Act which requires an employer to monitor the employees' exposure to the hazard. However, in order for the hazard identification and management system to be effective, adverse health effects associated with manufactured nanomaterials need to be more clearly identified and the technologies for assessing the hazard and controlling it must improve.

Residues in foods are controlled by either the New Zealand (Maximum Residue Limits of Agricultural

86 Such as toxicity, ecotoxicity, explosiveness, flammability, corrosiveness and ability to oxidise.

Compounds) Food Standards 2006[87] if contamination arises from use of pesticides or veterinary medicines, or the Food Standards Code[88] established by Food Standards Australia and New Zealand (FSANZ) for other sources of food contamination. Both these pieces of legislation are able to cope with residues containing manufactured nanomaterials when the need arises.

Future regulation

It is generally recognised that more research is required to understand potential adverse effects of different types of nanoparticles (toxicity, exposure pathways, and mechanisms of action), to develop methodologies, instrumentation and international standards to detect and monitor such particles, and to develop adequate exposure control strategies. Much of this research is being or will be conducted in other countries and would not need to be duplicated here. However, some novel materials developed and produced in New Zealand are likely to require data on human and/or environmental effects. There will also be a need for local research associated with potential impacts on unique New Zealand environments or species to inform regulatory assessments.

Researchers producing manufactured nanomaterials will not necessarily have the expertise to study potentially hazardous properties of these materials and so need to establish collaborations with research groups that have complementary expertise in risk assessment.

Uncertainty over regulatory requirements of manufactured nanomaterials can also impede research and development. Consequently, clarity over regulatory requirements is desirable. Many countries are considering the regulatory implications of manufactured nanomaterials and so cooperating with other countries to clarify regulatory issues will expedite the process.

Ethics

Discussions of the ethical implications of nanoscience and nanotechnologies are focussed on general ethical implications of new technologies, rather than specific implications for particular nanotechnologies. In New Zealand ethical approvals are not currently required specifically for R&D at the nanoscale. Certain types of research, such as the involvement of human subjects or animals, routinely undergo ethical oversight, and so such research that involves nanomaterial would receive ethical review. In addition, the HSNO Act provides for the ability of cultural, ethical and spiritual issues to be considered during regulatory assessments of hazardous substances and new organisms. As developments in nanoscience and nanotechnologies occur, it may be appropriate to review the provisions for ethical oversight in this area.

87 http://www.nzfsa.govt.nz/policy-law/legislation/food-standards/mrl-2006/nzmrlfs2006-consolidation.pdf.

88 http://www.foodstandards.gov.au/thecode/foodstandardscode.cfm.

Statement of direction: regulation

Direction 9

The Government will ensure that regulatory arrangements are appropriate for managing nanoscience and nanotechnologies.

The focus will be on enhancing our capabilities to effectively and efficiently identify and manage risks associated with manufactured nanomaterials.

Immediate actions (2007):

- Researchers producing and studying manufactured nanomaterials of uncertain risk potential shall develop linkages with other research groups that have expertise in assessing toxicity, ecotoxicity, and other hazardous effects to establish hazardous properties of new materials.
- FRST and HRC to require that research programmes help develop New Zealand's capabilities for risk assessment of manufactured nanomaterials.
- Regulatory agencies to continue clarifying policy in relation to how novel properties associated with manufactured nanomaterials will trigger assessments.
- MoRST to discuss with Australian government agencies the potential for collaborative research and information sharing in relation to risk assessments of manufactured nanomaterials.
- The Government continue to support and engage with international initiatives to coordinate nanotechnology policy developments (such as OECD and other relevant international standard setting organisations).

The nine directions are summarised in Table 5.

Table 5

Summary of the directions for New Zealand nanoscience and nanotechnologies.

TIME FRAME		
2007-2010	2010 to 2015	Beyond 2015
Goal: Enhance absorptive capacity and R&D capabilities in nanoscience and nanotechnologies.		
Direction 1 Basic research that contributes to the understanding and exploitation of novel properties that emerge at micro- and nanoscales and builds critical mass.		
	Direction 2 Research targeted to proposals that show strong relevance and benefit to existing industries.	
		Direction 3 Development of more transformative applications that may lead to the formation of new industries.
Direction 4 Build capabilities in bio-nanotechnologies.		
Direction 5 The needs of existing New Zealand industries should inform research.		
Direction 6 Ensure the appropriate tools and skills are available to underpin the research directions.		
Direction 7 Nano-related research and policy should be informed by social research.		
Direction 8 Support development of inclusive forms of public engagement.		
Direction 9 Ensure that regulatory arrangements are appropriate.		

6 Putting the Roadmap in place

This Roadmap has been approved by the Minister of RS&T, who will retain stewardship of the Roadmap and, supported by MoRST, will ensure that the directions are communicated and actions taken.

The Minister of RS&T will instruct FRST and the HRC to take account of the relevant directions in the Roadmap in their future investment decisions.

The Minister of RS&T will also encourage organisations in the wider science system to take account of the Roadmap's directions. These include policy, funding and regulatory agencies which have been involved with the Roadmap process.

MoRST will maintain leadership for coordinating policy development and strategic activity to ensure responsible management and development of nanoscience and nanotechnologies in New Zealand.

This Roadmap is intended to be a statement of the Government's position on nanoscience and nanotechnology RS&T in New Zealand and is expected to remain current for five to ten years. It is, however, inevitable that unforeseen developments will occur and that some of these may, in time, alter the outlook of the Roadmap.

MoRST will maintain oversight of the Roadmap, advising the Minister of RS&T on the progress of implementation as well as the ongoing relevance of its directions. MoRST will maintain a Roadmap steering group to provide feedback on progress and arising issues. The Minister of RS&T will consider the need for an update to the Nanoscience and Nanotechnology Roadmap by 2011.

We will know that the Roadmap is having the intended impact on research and policy direction through a variety of indicators (see Table 6).

Table 6

Indicators of the Nanoscience and Nanotechnologies Roadmap's success.

Area	Indicators of success in next five years
Research	New Zealand researchers publish highly cited papers in leading journals on the creation and characterisation of nanoscaled or nano-structured materials and devices, and hold influential patents or other intellectual property.
Research	New Zealand has developed strong capability in bio-nanotechnologies.
Research	New Zealand nanoscience and nanotechnologies are being informed by social research on New Zealand values and expectations.
Infrastructure	New Zealand researchers have cost-effective access to key infrastructure related to nanoscience and nanotechnology, both in New Zealand and elsewhere.
Interdisciplinary teams	Interdisciplinary research teams involving biologists, physicists, chemists, engineers and/or social scientists continue to emerge.
Secondary education	Teachers have examples of New Zealand nanoscience and nanotechnologies research that can be used as part of the curriculum.
Tertiary education	Courses related to the nanosciences and nanotechnologies are continuing to attract under-graduate and post-graduate students, and produce skilled researchers and business-savvy scientists.
International	New Zealand has contributed to setting international standards associated with nanoscience and nanotechnologies.
Societal engagement	Nanoscience researchers, with the support of their organisations, are involving communities in discussions of research and potential applications.
Commercialisation	New Zealand companies are beginning to inform nanoscale R&D, and New Zealand R&D is being licensed/taken up by companies elsewhere.
Regulation	Regulatory guidelines are clear about what properties of manufactured nanomaterials will trigger regulatory assessment and what the assessment criteria are.
Governance	Clear and consistent government policies supporting innovation as well as assurance.

Annex I

Documents that have informed this Roadmap

National Nanotechnology Initiative (2006). "Research and Development Leading to a Revolution in Technology and Industry. Supplement to the President's FY 2007 budget."
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http://www.wilsoncenter.org/news/docs/macoubriereport.pdf

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http://www.nanotec.org.uk/finalReport.htm

United States Department of Agriculture (September 2003). "Nanoscale science and engineering for agriculture and food systems." A report submitted to Cooperative State Research, Education and Extension Service, The United States Department of Agriculture.

Arnall AH (2003). "Future Technologies, Today's Choices. Nanotechnology, Artificial Intelligence and Robotics; A technical, political and institutional map of emerging technologies." A report for the Greenpeace Environmental Trust. July 2003.
http://www.greenpeace.org.uk

"New dimensions for manufacturing. A UK strategy for nanotechnology." Report of the UK Advisory Group on Nanotechnology Applications submitted to Lord Sainsbury, Minister for Science and Innovation by Dr John M Taylor, Chairman. June 2002.

Annex 2

A summary of international investment in nanoscience and nanotechnologies

In many countries nanoscience and nanotechnologies are attracting considerable funding from governments (see Table A), particular industries, and some private sources. However, while these figures can look impressive, gross domestic expenditure on all R&D in the OECD and nine non-OECD countries in 2004 was approximately US$836,000 million. About 30% of this, or US$250,000 million, was financed by governments[89]. Public "nanotechnology" investment is thought to be about 1.5% of total government R&D spending.

Table A

Estimated Government Nanotechnology R&D Investments in 2003-2005 (US$ Millions). Source: President's Council of Advisors on Science and Technology (2005). "The National Nanotechnology Initiative at Five Years: Assessment and Recommendations of the National Nanotechnology Advisory Panel". Other sources produce slightly different figures, but show the same trends and high levels of investment.

	Government investment (US$ millions)		
Region	**2003**	**2004**	**2005**
EU	~ 650	~ 950	~1,050
Japan	~ 800	~ 900	~ 950
USA	862	989	1,081
Others	~ 800	~ 900	~1,000
Total	~3,100	~3,700	~4,100

However, it is difficult to accurately quantify investment or make direct comparisons between countries. This is due to differences in how countries and organisations define nanotechnology, and quoted figures may or may not include salaries as part of R&D. Nonetheless, several governments have made significant investments in nanotech R&D in the last five years and this trend is likely to continue (PCAST 2005[90]).

Nanoscience and nanotechnologies are being viewed as presenting new manufacturing opportunities and underpinning future competitiveness across a range of sectors, as well as contributing to sustainable development. Many countries are supporting nanoscience and nanotechnologies to support existing competitive advantages.

89 OECD, Main science and technology indicators, November 2005.

90 http://www.nano.gov/FINAL_PCAST_NANO_REPORT.pdf.

Current leaders in nanoscience and nanotechnologies are the United States of America, Japan, South Korea and Germany. However, Taiwan and China are anticipated to become significant players in the near future due to well coordinated initiatives in Taiwan, and China's growing research excellence and facilities in some nanotechnologies[91].

The USA has made nanotechnology R&D a top priority because of its potential to promote innovation and economic benefits and to strengthen the position of the USA as a leader in science and technology. Government investment in nanoscience and nanotechnologies represents about 1% of total government R&D investment.

The USA is not targeting particular industries for nanotechnology applications, as is occurring in some countries. For fiscal year 2004 the bulk of USA funding was allocated to the National Science Foundation (30% - the NSF largely supports fundamental research), the Department of Defence (26%), and the Department of Energy (23%)[92]. This general trend is continuing in subsequent budgets[93]. Estimates for the USA 2006 budget allocated the bulk of nanotechnology funding (approximately US$1300 million) to "nanoscale devices and systems" (23.1%), "fundamental nanoscale phenomena and processes" (22.2%), "nanomaterials" (21.6%) and "major research facilities and instrumentation acquisition" (14%).

The European Union, through its Framework Programme, is attempting to coordinate nanotechnology research across member states, and has invested substantially in nanomaterials, nanomedicine and nanoelectronics[94]. It has developed a nanomedicine technology platform[95] and a nanoelectronics technology platform[96]. Other nanotechnology platforms are also likely. One of the nine research themes for Framework Programme 7 is "Nanosciences, nanotechnologies, materials and new production technologies." A range of research consortia focussing on the nanoscale already have support from the European Union through programmes such as Framework Programme 6, for example NanoDerm[97], NanoSafe2[98], and Nano2Life[99].

Other countries are targeting particular types of nanotechnologies, as shown in Table B. Summaries of other countries/regions involvement in nanotechnologies can be found in Attachment F[100] associated with the US National Science Foundation's 2004 report "International Dialogue on Responsible Research and Development of Nanotechnology"[101]. In addition some large multinational companies are also investing in nanoscience and some have already placed products on the market. For example, personal care product companies such as L'Oreal and Unilever, the chemical companies DuPont, BASF, and Degussa, agricultural companies such as Syngenta, food companies such as Unilever and Nestlé and computer companies such as IBM and Hewlett Packard.

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91 Lux Research press release November 3, 2005. "The US, Japan, South Korea, and Germany dominate in nanotechnology today – but Taiwan and China are rising". Available from http://luxresearchinc.com Accessed 24 March 2005.

92 http://www.nano.gov/html/res/IntlFundingRoco.htm.

93 See http://www.nano.gov.

94 European Commission. Some figures about nanotechnology R&D in Europe and beyond. Version: 8 December 2005. http://cordis.europa.eu.int/nanotechnology.

95 See http://www.cordis.lu/nanotechnology/nanomedicine.htm.

96 http://www.cordis.lu/ist/eniac/.

97 See http://www.uni-leipzig.de/~nanoderm/.

98 See http://www.nanosafe.org/.

99 See http://www.nano2life.org/.

100 http://www.nsf.gov/home/crssprgm/nano/1_attachment.pdf.

101 http://www.nsf.gov/home/crssprgm/nano/1_final_report.pdf.

Table B.

Nanotechnology strengths or focus in selected countries, and associated national strategies or initiatives.

Country	Particular nanotechnology strengths or areas of application	Strategies and/or funding
Australia	Materials, nano-biotechnology, electronics and photonics, energy and environment, and quantum computing[a].	AU$100 million (US$76 million) annually. Currently developing a nanotechnology strategy.
China	Nanomaterials, nanoelectronics and nanobiology[b].	More than half of government nanotech investment in China is directed toward nanomaterials. "National Nanotechnology Development Strategy" (2001 – 2010).
Germany	Nanoelectronics, nanomaterials, and optical science and engineering. Their automobile, optical, pharmaceutical, medical technology and electronics industries are seen as having the most to gain[c].	€129 million from Federal sources in 2005[d].
Japan	Electronics and medical applications, infrastructure and instrumentation[e].	US$950 million in 2005.
South Korea	Electronic applications, devices and materials.	US$1.5 billion from government and industry for the ten year plan - "Plan for Promotion of Nanotechnology" (2001-2010).
Taiwan	Nanoelectronics.	US$630 million allocated between 2003 and 2008 as part of "National Nanotechnology Program".
United Kingdom	Electronics and communications; drug delivery systems; tissue engineering; medical implants and devices; nanomaterials; instrumentation, tools and metrology; and sensors and actuators[f].	£40 million for facilities development, and £50 million for grants in 2003 as part of the UK Strategy for Nanotechnology – 2002[g]. Micro and Nanotechnology Manufacturing Initiative -2003[h]. Additional investments through other government funding schemes have also been made.

a "Australian Nanotechnology. Capability & commercial potential. 2nd Edition." Australian Government.
See http://www.investaustralia.gov.au/index.cfm?menuid=0DA5E4E7-B0D0-36D2-5C0BF55FC0AAA99D&setLanguage=AU.

b Gu H, Schulte J. (2005). "Scientific development and industrial application of nanotechnology in China." In Schulte J (ed.), Nanotechnology: Global strategies, industry trends and applications. John Wiley & Sons. Pp 7- 24.

c "Nanotechnology - A future technology with Visions". Federal Ministry of Education and Research.
Available at http://www.bmbf.de/en/nanotechnologie.php - Accessed 27 March 2006.

d "Germany's nanotechnology strategy" R&T Note No. 011.04, April 2004. British Embassy, Berlin. Available from
http://www.britischebotschaft.de/en/embassy/r&t/notes/rt-note04.1011_nanotechnology_strategy.htm - Accessed 27 March 2006.

e See the PCAST 2005 report. Available at http://www.nano.gov/FINAL_PCAST_NANO_REPORT.pdf.

f "New dimensions for manufacturing. A UK strategy for nanotechnology". Department of Trade & Industry (2002).

g "New dimensions for manufacturing. A UK strategy for nanotechnology". Department of Trade & Industry (2002).

h See http://www.microandnanotech.info/.

Annex 3

Examples of sector reports that evaluate the contributions nanoscience and nanotechnologies can make

- "Environmental technologies at the nanoscale". Masciangioli T & Zhang W-X. Environmental Science and Technology, March 1, 2003. Pp 102A - 108A.
- "Nanoscale science and engineering for agriculture and food systems". A report submitted to Cooperative State Research, Education and Extension Service, The United States Department of Agriculture. (September 2003). http://www.nseafs.cornell.edu/web.roadmap.pdf
- "Chemical Industry R&D Roadmap for Nanomaterials By Design: From Fundamentals to Function." Chemical Industry Vision2020 Technology Partnership. (December 2003). http://www.chemicalvision2020.org/nanomaterialsroadmap.html
- "Cancer nanotechnology plan. A strategic initiative to transform clinical oncology and basic research through the directed application of nanotechnology." US Department Of Health and Human Services (July 2004). http://nano.cancer.gov/about_alliance/cancer_nanotechnology_plan.asp
- "Energy and nanotechnology: strategy for the future". James A. Baker III Institute for Public Policy of Rice University. (February 2005). http://www.rice.edu/energy/publications/index.html
- "Cancer nanotechnology: opportunities and challenges". Ferrari M. In Nature Reviews Cancer. Vol 5(3), pp 161-171. (March 2005).
- "Nanoforest. A nanotechnology roadmap for the forest products industry." STFI-Packforsk report no. 48 (September 2005). http://www.stfi-packforsk.se/upload/3352/Finalroadhem.pdf
- "European Technology Platform on Nanomedicine". European Commission (September 2005). http://cordis.europa.eu.int/nanotechnology/nanomedicine.htm
- "Forward look report on nanomedicine". European Science Foundation. (2005).
- "European Nanoelectronics Initiative Advisory Council Strategic Research Agenda". European Commission (November 2005). http://www.cordis.lu/ist/eniac/
- "International Technology Roadmap for Semiconductors" (2005). http://public.itrs.net/

Annex 4

Summary of a case study of how social research can contribute to biophysical research programmes

The following is a summary of a longer case study that MoRST commissioned to identify issues in collaboration between social and biophysical scientists.

The research brief

MoRST commissioned Taylor Baines & Associates of Christchurch to produce a case study into collaboration between social scientists and biophysical scientists in the emerging science areas of nanotechnology and biotechnology. The case study was commissioned to help in developing a science roadmap for nanotechnology setting out directions for this new area of science.

Like any new area of scientific research, nanotechnology needs to meet societal values and expectations and MoRST wanted the study to explore "the practical benefits resulting from collaboration between social scientists and nanotech researchers" in meeting those wider community expectations.

In preparing this report the researchers investigated research projects in New Zealand and the UK where social scientists and biophysical researchers had worked together.

The research methodology

The research was carried out by Fitzgerald Applied Sociology on behalf of Taylor Baines & Associates and drew on the experiences of three collaborative projects.

The first project was a collaboration between a social scientist and a materials nanoscientist – both based in New Zealand. This was aimed at exploring the different perspectives and disciplinary culture of the two branches of science and what collaboration between the two might involve.

The second involved a social scientist in the UK who was recruited by a specialist nanoscience research centre to be an active participant in their research work.

The third case study involved a New Zealand-based biological scientist working in the area of possum biocontrol and involved in a study that explored the interactions between science, regulatory agencies and communities. The interviewer conducting the case study was previously involved in this project.

Separate interviews were held with each of the above scientists. Social scientists working in the area of pest biocontrol and in a range of New Zealand government and private sector research institutions provided additional comments and background information. This was supplemented by background information from the websites of relevant organisations.

General issues around social science

The term "social science" covers a wide range of disciplines such as psychology, sociology, geography, anthropology, economics and political science – in other words, disciplines that study human beings, their interactions and organisation.

While there is some debate about whether the social sciences are subject to "scientific laws" in the same way the physical sciences are, the use of the term science is justified by social scientists on the grounds that they use systematic research methods to gather data along with various forms of explanation to help understand it.

In New Zealand, there are few social scientists employed in physical or biological research programmes on an ongoing basis. If they are employed in science institutions such as CRIs, they are generally not engaged in the science work first hand. Rather, they may have an add-on role in large biophysical research projects as opposed to being integrated into the main project team. In other cases, they may be there to supply social market intelligence, including identifying the social risks and costs, to facilitate public and stakeholder engagement, manage conflict, or assist in technology transfer.

As a result, true collaboration between social and physical scientists is rare.

Examples of collaboration in New Zealand

The single example of collaboration between social and physical scientists in nanotechnology in New Zealand was a project aimed at preparing and presenting a seminar paper on the technology and the interface between the science and society.

The two researchers involved met once a week to brainstorm ideas which were then entered directly into a PowerPoint presentation.

Social research was also used to provide information about public attitudes to using biological controls of possums and rabbits. The social researchers conducted focus groups on the question of fertility control of the pests and the issues surrounding the use of genetic modification (GM) as a biocontrol. The biophysical scientists attended the focus groups to answer questions about their research and to get a first hand appreciation of the viewpoints of the various stakeholders. The findings of this research were used by the New Zealand Parliamentary Commissioner for the Environment in preparing his 2000 report "Caught in the Headlights: New Zealanders' reflections on Possums, Control Options and Genetic Engineering."

Examples of collaboration in the UK

The researchers for this case study examined a UK-based nanoscience collaboration involving a single social scientist working for a fixed term within a nanotechnology research organisation.

The social scientist ran workshops to inform nanoscientists about the social and ethical issues of nanotechnology, gave talks and presentations at science festivals and conducted social science research within the science setting. The social scientist was also responsible for facilitating public involvement in the NanoJury UK process. In this exercise, the UK's nanotechnology policy was put "on trial" in front of a citizens' jury as a way of involving the public in the development of policy of this new area of research. The jury heard from various witnesses who talked about the pros and cons of nanotechnology and then came up with a series of recommendations for policy makers.

The challenges of social and physical science collaboration

The interviews with social scientists and their colleagues in the physical sciences pointed to a number of challenges in interdisciplinary collaboration.

These included:

Language differences

The various disciplines use very specific language in discussing their area of research. Collaborators need to be prepared to ask for clarification so that each side can build up their knowledge in the other subject area. There is a further challenge in articulating this knowledge and language to other groups, including community groups. Biophysical scientists also commented that they can find social science language vague and imprecise.

Differing research methodologies

Biophysical scientists, used to formal experimental methods, can also be dismissive of social science methods, particularly qualitative research and the less tangible data it yields. Those interviewed suggested attitudes among biosphysical scientists changed as the benefits of the social science approach were demonstrated.

Differing viewpoints

Both the language differences and the differing research approaches are part of a deeper challenge – namely the differing philosophical assumptions that underpin the two disciplines. The British researcher interviewed for this research report stressed, however, that it was important the different perspectives were maintained in order to get the best out of the collaboration and warned against the social science researcher becoming "too embedded" in any collaborative project.

Ensuring the role of the social scientist is understood

Social scientists spoken to for this study reported that it could be difficult for them to find concrete ways to contribute directly to nanoscience research projects, and that the literature can also be challenging. The British social scientist interviewed put it this way: "The big challenge was to reject the framing that public and social issues weren't connected to research practice and science work in general." This can be linked to a sense, within the biophysical sciences, that the practice of science in the laboratory is value-neutral, meaning that the social and political context of the research is not taken into account.

The "they'll put it right" approach

By bringing a social scientist into a research project, the assumption was that this alone would automatically lead to the development of less contentious technology. The British social scientist interviewed made it clear that "collaborations may be able to highlight tensions and provide a language for debate about the role of science and technology in society, but (they) cannot replace wider public deliberation" on a potentially contentious area of scientific and technological research.

Being taken seriously

Some participants reported that it was difficult to get collaborative work involving social scientists published in mainstream science journals. They also felt that it was difficult to identify what social science might bring to the practice of biophysical science and that the collaboration had not always brought about a real change in the science.

Collaboration can be time consuming

The research for this case study also highlighted that social science collaboration in the nanotechnology field requires time. The social scientist needs an extended placement in the laboratory if they are to fully understand the technology. The British social scientist suggested an ethnographic approach, using close field study of the social and cultural aspects of the community, as an appropriate approach in a successful collaboration.

The benefits of collaboration

Despite the challenges of collaboration between social and biophysical scientists, those who took part in this study said there were real benefits from such collaboration – although these could be unpredictable and not easily quantified. The following benefits were identified:

Building new networks

Ideas and opportunities for further collaborative work often resulted from an initial collaborative project. In the case of the UK nanotechnology project, links were developed and strengthened between a wider range of science stakeholders such as science policy makers. The relationship also saw the social scientist embedded in the project facilitating the participation of nanoscientists in a national-level social science discussion on nanotechnology policy (the UK NanoJury).

Personal knowledge of another scientific discipline

Being exposed to another scientific discipline allowed social scientists to communicate better in a cross-disciplinary situation. As a result, the social scientists were also better able to get across community concerns about the particular technology or research to the biophysical scientists. The collaborative work also allowed the biophysical scientists to better understand public viewpoints on their works and why they held these views.

Heightened awareness of the social and political context of research

By challenging the idea that society and its interest begins outside the laboratory door, the social scientists involved in collaborative projects were able to soften the sometimes dismissive attitudes of biophysical scientists to the public and their concerns. In the case of the pest biocontrol research collaboration, this new awareness led to the research priorities being reworked and to a clearer definition of the outcome sought. Communications and risk management strategies were also developed to assist in community engagement over the biocontrol technologies. In the case of the UK nanotechnology project, the collaboration has resulted in advice to government on processes to reduce the chances of public controversy regarding nanotechnology. It has also demonstrated how public discussion of a potentially contentious area of science can be a positive experience, provided democratic processes are used early on in the development of the technology.

Broadening horizons

Respondents reported that the exposure to different viewpoints was one of the surprise benefits from cross-disciplinary collaborations. It led them to reflect on their own approach to their particular area of research, whether it be social or biophysical, and to recognise the assumptions that underpinned it. One participant reported that, through their collaboration, they had gained the ability to "read between the lines" and deconstruct their own and others' work. A biophysical scientist, who admitted being very sceptical of the qualitative research approach of social science, reported gaining an appreciation of the value of this approach.

Conclusions

There is evidence that social science work can make an important contribution to collaborative projects. In the case of the UK NanoJury exercise, social scientists encouraged public engagement and facilitated a discussion that could have far-reaching implications for the direction of nanotechnology research and policy in the UK.

In New Zealand, social science influenced the direction for biotechnology research for pest control, leading to socially unacceptable forms of biocontrol being discontinued.

There are, however, lessons to be learned from these experiences. These are:

- There needs to be an investment of time in the early stages of collaboration to discuss any issues related to the collaborators' work and how the project might proceed.
- The social science aspect of the collaboration needs to be incorporated into the design of the science projects from the beginning, rather than being "tacked on" later as an afterthought.
- Funding agencies need to give greater recognition to social and biophysical science collaborations and requirements for studying the social, ethical and cultural dimensions of a technology under development should be attached to funding. Funding should also be made available to monitor and study how collaboration is being done.

- A team approach could be used for the social science component of collaborative projects. This would involve one researcher "embedded" with the science team as a participant in the work, while other social scientists worked as a team to carry out more traditional social science based on observation. This would allow the social science team to maintain a level of autonomy.
- Not every scientist (social or biophysical) will want to be part of a collaborative team, or be suited to this sort of work. The successful collaborations are more likely where the individuals involved are already working across disciplines. In putting together a team, the following are important considerations:
  - trustworthiness;
  - approach to work;
  - pace of work;
  - feelings about publication;
  - agreement on the standards and amount of work involved;
  - a basic belief that social science is of the same value as biophysical science;
  - an open mind about the various approaches to research; and
  - being prepared to debate with, and listen to, others.

ROADMAPS for SCIENCE

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