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Nanotechnology Applications and Opportunities for Australia

EMERGING INDUSTRIES
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COMPETITIVE AUSTRALIA

Smaller, Cleaner, Cheaper, Faster, Smarter

Nanotechnology Applications and Opportunities for Australian Industry

June 2002

A Report for the Commonwealth Department of Industry, Tourism & Resources

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“Nanotechnology will give rise to a new generation of medical devices: combined with advances in molecular biology it will lead to treatments that are not dreamed of today.”

Jim Patrick
Senior Vice President of Research
and Applications Cochlear Ltd

"The 21st century will be a period of substantial progress for nanotechnology as researchers focus on innovative technologies aimed at advancing the evolution of the Internet and developing technology solutions more closely linked to people's everyday lives.

Fujitsu’s Nanotechnology Research Center in Japan is testament to its commitment to this cutting-edge research."

Mr Phil Kerrigan
CEO Fujitsu Australia Limited

“Nanotechnology is an exciting part of science that will generate step changes, brave new opportunities and outstanding applications. We have the opportunity in Australia to significantly resource this area and indeed see it already as a key priority for Australian science. This report will be an extremely useful collection of contacts for those working in the field of nanotechnology and its applications.”

Dr Robin Batterham
Chief Scientist, Commonwealth of Australia,

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About this Report

About this Report

This report has a number of objectives.

First and foremost, this report is about raising awareness in the wider business and investor community about what nanotechnology is; what it is not; highlighting which Australian companies are already engaged in developing or using nanotechnology; and how other Australian companies and diverse industry sectors could benefit by applying these technologies.

The main objectives of the report are therefore to:

i) Make clear that it is the applied industrial benefits and attributes of the technology that are important - not any academic mystique about "nanotechnology".

ii) Explain in simple terms what nanotechology is today, and highlight the potentially major impact it may have on global industries;

iii) Provide some case examples of how this technology is being applied by leading-edge Australian companies; and

iv) Illustrate opportunities in nanotechnology by outlining examples of "imaginings", these being product-concepts under development in Australian research institutes.

An ideal outcome is to inspire interest and ignite the imagination of Australian companies, across a range of industry sectors, to see where and how they may gain future competitive advantage by adoption of nano-scale technologies in their manufacturing processes.

This report is only indicative of the many applications within the field. It is not a comprehensive log of national nanotechnology-based applications; nor a compendium of research activities ongoing across Australia; nor a comprehensive academic analysis of the field. References at the end of the report will provide inroads to the nanotechnology literature, which is growing explosively.

Rather, this report is written as a short and easy to comprehend explanation, covering the basic concepts, leading into case studies illustrating areas of current and future application. The examples of "imaginings" are selected to highlight Australian-based endeavours in this area.

The report is broken into four sections.

The first part describes what nanotechnology is, and is not, as presently defined by the underlying fundamental science, and grounds this description in an industrial context.

The second part illustrates nanotechnology applications being pursued by various Australian companies. Ten case examples are highlighted across diverse industry sectors.

This section is followed by examples of nanotechnology "imaginings". These are summaries generally representing embryonic nanotechnology-related "product concepts" that are presently incubating in universities and research institutions across Australia. These imaginings typically require further intensive work and investment to advance and commercialise the "imagining". It is emphasised that these examples are illustrative, not a comprehensive national catalogue.

The final section is an Appendix that provides sources of further information and indicates the networks of organisations and expertise that are presently linking together as stake-holders, all being interested in the industrialisation of nanotechnology.

This report has been produced by Ernst & Young (Sydney), on behalf of the Commonwealth of Australia represented by the Department of Industry, Tourism and Resources.

This report is in part a follow up to an earlier report provided by Ernst & Young, in collaboration with Freehills Technology Services and Howard Partners, to the Commonwealth entitled "Scoping Study into Nanotechnology Technology Diffusion".

The authors thank the Department of Industry, Tourism and Resources for the opportunity to compile this report.

The authors wish to extend special thanks to the busy individuals in the companies and organisations who contributed to this report.

The authors have drawn on the reports and work of others in the creation of this document. Where appropriate we have provided attribution to these works.

Ernst & Young
31st May 2002

Nanotechnology

1. What is Nanotechnology?

Summary - Scientific discovery has long followed a reductionist theme, examining matter in smaller and smaller sizes down to molecular, atomic and sub-atomic size.

Scientific research over recent decades has examined matter at the nano-scale, in multi-disciplinary fields such as biology, physics and chemistry. This has lead to discoveries and knowledge that has inspired nano-scale industrial technology. This is the ability to deliberately engineer matter at this small scale, either by making particles/matter uniformly smaller, or scaling up matter using nano-sized building blocks.

The potential industrial applications of these technologies are many and varied.

The proponents would argue the world to be entering a new nano-led industrial age; the realists note that industrial uptake of such technologies will depend on improved performance and cost benefits, thereby delivering superior technology that is embedded in products that are *smaller*, *cheaper*, *cleaner*, *faster* and *smarter* than those existing.

1.1 How will nanotechnology impact on Australian industry?

From an industrial exploitation and applications perspective, nano-scale engineering of matter offers future products and processes with improved benefits and attributes over those existing. These benefits will be manifest by, for example, "smaller, faster, smarter, cheaper, safer, and cleaner" products and processes - in other words, practical and cost effective performance benefits of nano-scale components in manufacturing.

Such attributes, if captured in products, are the basis of firm-level competitive advantage. If successfully and widely integrated across manufacturing industry, they become the basis of a more competitive national economy - which is why governments world-wide are now committing vast resources to nanotechnology.

The major players in the nanotechnology field are the USA, Japan and Western Europe. Estimates of international expenditure on nanotechnology are shown in Table 1.

Table 1: Estimated Government Spending on R&D in Nanotechnology in $US millions/year[1]

	1997	2000	2001
W Europe	126	184	
Japan	120	245	431*
USA	116	270	423
Total	362	624	

*from http://www.foresight.org

One estimate indicates two billion US dollars of government money has been invested in the development of nanotechnology worldwide over the last two years[2]. Despite this enthusiasm, there is limited understanding by industry as to the science behind nanotechnology nor appreciation of the vastness of possible applications it may have across a broad spectrum of industries when it is applied appropriately.

1.2 How is, or will, nanotechnology be applied industrially?

This is emerging in broad and extensively overlapping categories of platform or enabling applications. The scope of activities and the types of potential industry applications are summarised below in Table 2.

1.3 How far away from market are nanotechnology-related products?

The answer to this question risks being bogged in definitional debate as to what is meant by nanotechnology. Setting this aside, the following are (debatable) generalisations as to the current state of the field, and extent of industrial application:

There are more "product/technology concepts" under active development than there are in the applications in market. The majority of the existing nanotechnology effort still lies at the R&D phase, incubated in research institutions, and also proof of concept or pre-commercialisation phase being championed by emerging companies. This is true of the USA, EU and Asia, and Australia (where there are fewer active players and companies). Market applications of nanotechnology are still predominantly at "science-push" phase.

- The more advanced applications in the market are in industrial uses of nano-particles eg metal/oxide, biomedical and electronics/photonics area. There is a growing market for precise and uniform sized nano-particles eg metal oxides, with this sector comprising the majority of new start-up companies (both in USA and Australia).
- Companies that have nanotechnology as a core capability (or highly significant) to their business model

Table 2: Summary of Potential Industrial Applications Arising from Nanotechnology.

Technology Impact and/or Product	Example of General Industry Application
Next generation semi-conductors, nano-scale lithography opto-electronics and magnetics. Lasers, sensors, laboratory on a chip, displays, photonic devices and optical communication, microprocessors, computer peripherals, chip design. Stronger and lighter construction materials.	Electronics, photonics and computing technology. Information and communication industries, transport industries, defence industries, eg, avionics, satellites, communication systems.
Biomaterials, drug delivery, in-vivo monitoring devices and sensors (eg. pollution hazards or in detecting biological warefare), diagnostics and diagnostic equipment, nano-prosthetics, bio-mimetics and bio-chip technology (eg. DNA/protein chips).	Human and animal health industries, eg. pharmaceuticals, food production and processing. Environmental monitoring eg. remote sensing.
Molecular motors, energy storage and saving systems, sensors, water and/or purification, air purification, environmental monitoring, remediation, products that reduce manufacturing waste, capacitors and battery materials, degradable/food packaging systems.	Energy and utilities sector, environmental industries.
Nano powders, particles/metals/metal oxides, carbon structures for use in materials, alloys, ceramics, polymers, inks, coatings, cosmetics. Includes catalysis, separations, absorption, magnetic fluids and materials, membranes, molecular sieves, prostheses, lightweight structures, metal/polymer composite, fibres/textiles.	Manufacturing industries. Mining and minerals. Transport industries, eg aerospace, construction industries.

1 According to M.C. Rocco, senior advisor NSF www.nsf.gov/home/crssprgm/nano/nni11600/sld001.htm.nano the Chair, NSTC's Sub committee on nanoscience.
2 CMP Citentifica 2001

are typically[3] in start-up/early growth phase, they have limited revenue and are R&D intensive entities.

- Big corporates that have been early investors in, or early adopters of, nanotechnology are those that have long competed through innovation eg Fujitsu, Samsung, IBM, Lucent, etc.

The following is an illustrative example of a US company that has grown to a stage of becoming a supplier of nanotechnology products, and has a far longer history:

> **Nanometrics Incorporated** ("Nanometrics") was founded in 1975 and listed on the Nasdaq since 1984. The company designs, manufactures and markets advanced thin film and overlay metrology systems. Nanometrics is a leading supplier of semiconductors to mainly metrology services and magnetic recording head industries. The microelectronic components of the semiconductors are made of deposits of thin layers of semiconductive materials. Nanometrics has found that the thinner the films are, the faster these devices conduct, creating more sophisticated and specific semiconductor devices. Total revenues for the fourth quarter 2000 were US $17.2 million.

1.4 So what does nanotechnology mean?

On a mathematical level, a nanometre (abbreviation "nm") is equivalent to one billionth of a metre. If one millimetre is divided into one million equal parts; each part would be a nanometre.

1 metre = 100 centimetres (cm)
= 1,000 millimetres (mm)
= 1,000,000 micrometres (μm)
= 1,000,000,000 nanometres (nm)

On a scientific level, nature has through evolution established building blocks in the nano-scale. The fundamental building blocks of life include: atoms that are assembled into molecules; molecules that aggregate to form polymers, membranes and cells/tissues, and eventually, whole organisms.

This is replicated across all species - plant or animal or micro-organism. Research has shown that the fundamental biochemical and biomechanics of life are often founded on structures broadly within the 1 - 100 nm size range.

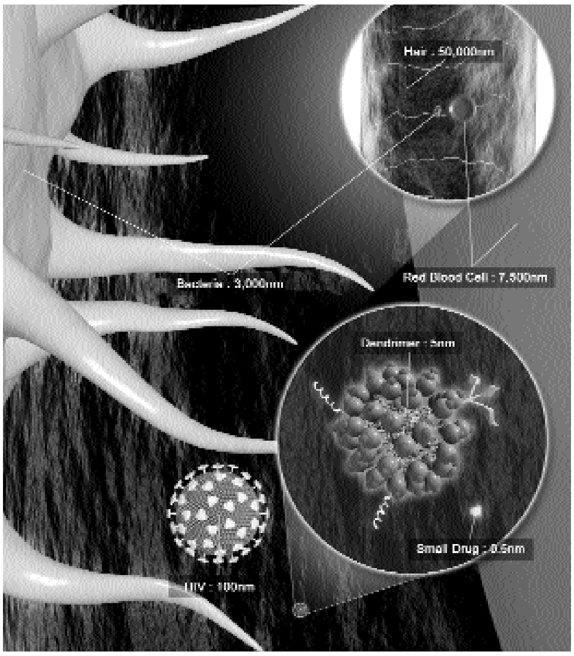
[3] See http://www.homestead.com/nanotechind/companies.html

Therefore to help conceptualise the idea of nanotechnology both at a mathematical and scientific level, consider a human hair. On a relative scale - the width of a human hair is about 50,000nm wide. Looking deeper inside our body, for example the width of a red blood cell circulating through our system is approximately 7,000nm wide, whereas a bacterium that lives inside our system is 1,000 nm wide. These would be considered organisms or structures on the micro-scale.

In comparison, focusing on the nano-level, a harmful virus is generally about 100nm wide and a conventional pharmaceutical drug generally about 1 nm in size (Figure 1).

It is on this degree of small scale that the realms of nanotechnology are being explored.

Figure 1: Relative sizes of nanoparticles



At a relative level, the difference in sizes between a metre and nanometre, can be roughly equated to the relative size of the size of the earth (1 metre) to a tennis ball (1nm).

Alternatively, on a time scale - if a nanometre equalled one second in time, then a metre would be equivalent to almost 32 years of time!

Decades of fundamental research in physics, chemistry and biology, at the sub-nano (quantum), nano and larger scale ie "nano-science and discovery", now beckons opportunities for application of this knowledge in nano-scale technologies. Figures 2 and 3 tell this story.

Figure 2: The Evolution of Precision Machining[4]

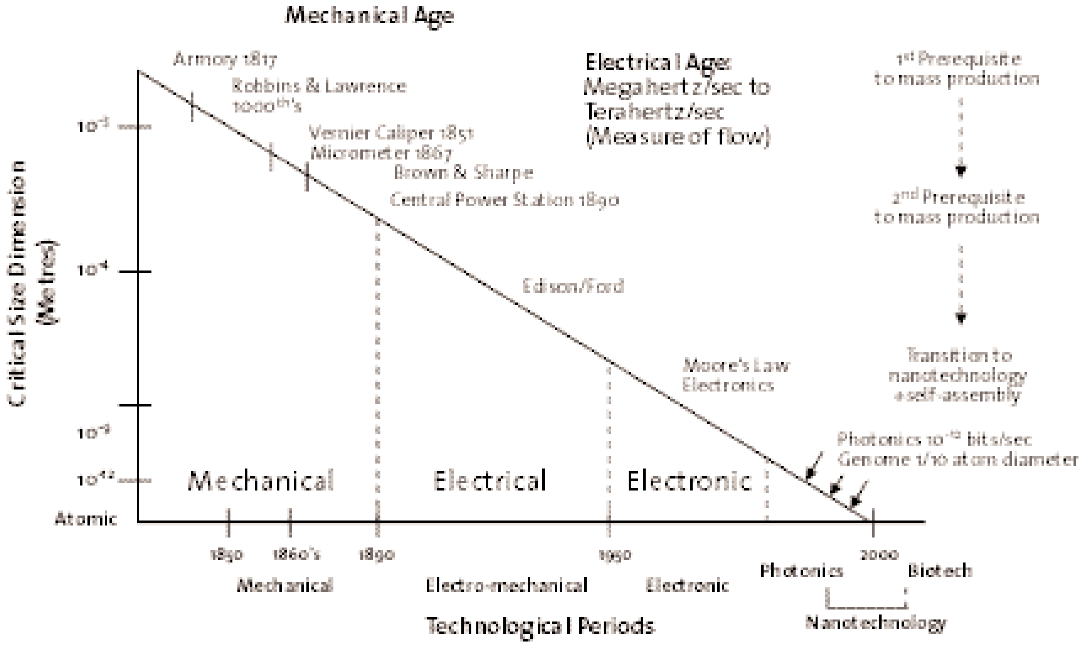


Figure 2 shows historically the ever-greater miniaturisation in technology, eg in precision machining. This leads to the prediction (or speculation) of the coming nanotech age - an inevitable change in advanced manufacturing processes.

Figure 3: Nanotechnology - Physics, Biology and Chemistry Integrated at the Nano-Scale.[5]

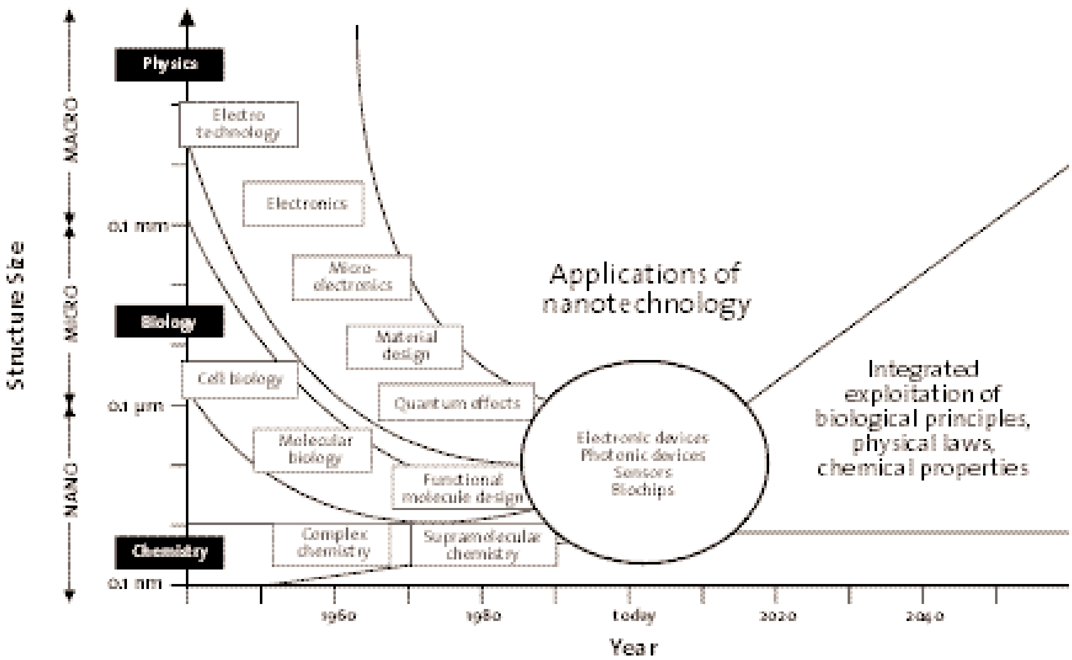


Figure 3 presents another key message - that nano-scale discoveries demand multidisciplinary capability and convergence. The future requires even greater multi-disciplinary integration of knowledge and resources in order to be academically or industrially competitive in the field. This means melding the discovery ethos of science and the design/build culture of engineers.

4 Adapted from http://www.niec.org.uk/documents/WayAheadInNorthernIreland.pdf

5 Adapted from Bachmanns (2001) 'Market Opportunities at the Boundary from Micro to Nanotechnology" MST News Vol 3(1) pp 13-14.

1.5 Working Definitions and Alternative Views about Nanotechnology

The following highlight definitions of nanotechnology, illustrating areas of differing emphasis.

Nanotechnology[6] *is (1) the creation of useful materials, devices, and systems through the control of matter on the nanometer-length scale, and (2) the exploitation of novel properties and phenomena developed at that scale.*

Or more simply...

Nanotechnology is the creation and use of materials, devices and systems that exploit novel properties arising from the structure and function of matter in the nano-metre range.

An alternative definition with an engineering insight is[7]:

Nanotechnology concerns a suite of technologies that allows every atom to be in the right place. It is about making almost any structure that can be specified in atomic detail. And it is also, eventually, having the manufacturing costs not greatly exceeding the costs of the raw material, atoms and energy.

Where do the experts broadly agree?

Nanotechnology is usually about objects and processes in roughly the 1-100 nm range. Sub-nano fields (eg quantum processes and sub atomic particle science) in not normally included, but clearly informs the field. It is generally agreed there are three *broad and extensively overlapping* categories of platform or enabling applications in nanotechnology, these being: nano-electronics/photonics; nano-materials/particles: and nano-biotechnology.

Where do experts differ in emphasis or interpretation?

Nanotechnology purists emphasise technology of objects/processes as being nano-scale in all three dimensions. Others are more flexible seeing nanotech as also including nanoscale two-dimensional interactions at *surfaces* eg membranes or micro-fluidic interfaces.

Some divide the nano-world into the "dry" and "wet" categories; "dry" generally meaning metal/oxide or carbon-lattice structures eg carbon-containing "balls" or "tube-forms"; whilst "wet" generally refers to nano-structures applied typically in the health and life sciences.

Some experts approach nanotechnology "top-down", their aim to make particles/matter more and more uniformly smaller to reach nano-scale. Others take a "bottom-up" view, their objective is to scale up matter using precise nano-sized building blocks to build bigger structures of exact design eg as scaffolds or nano-scale delivery systems for drugs or light channels etc.

Other experts see the field divided into tools; materials; electronics; biotech; and assemblers and indicate at least 250 companies world wide currently pursue commercial applications of nanotechnology, with about 10 percent of these having products in the market[8].

Is nanotechnology just smaller microtechnology?

Generally, the materials used in microtechnology behave as they would in 'bulk' objects. This may not be the case with nano-scale objects (< 100 nm), where physical properties may not mimic behaviours of bulk objects eg in conductivity, light emission/absorbance, stength, opacity, behaviour in magnetic fields etc.

Nano-scale materials can thus have *novel physical properties,* different from "bulk objects".

However, nano-scale materials may be incorporated in micro-scale components that in-turn may be incorporated in larger manufactured products – so the distinction between nano/micro/macro may be easily forgotten and hence blurred in scale up of products.

Has nanotechnology been long ongoing?

Some experts see nanotechnology as a "re-badging" of industry applications that have been long ongoing, these examples arising from leading edge discoveries in the physical, chemical and biological sciences. This view has some credibility.

For example, some companies have been engaged in developing very small (~100nm) particles in their products eg in the coatings industry, and would not think of this as being nanotechnology. Structure based design of a drug to

6 Published this year, "IWGN Workshop Report: Nanotechnology Research Directions. Vision for Nanotechnology in the Next Decade" (eds M.C.Roco, NSF; R.S.Williams, Hewlett Packard; P. Alivisatos, U.C. Berkley). A definition is offered in this book in the section under "Introduction to Nanotechnology for Nonspecialists" (p. xxxvi):

7 See commentary within company web site www.zyvex.com/nano/

8 See In Realis "A Critical Investor's Guide to Nanotechnology" February 2002 see http://www.inrealis.com

"dock" on viral surfaces[9] is also describable as nanotechnology.

A broader and far more positive perspective is that incremental progress in "nano-science and discovery" has been the essential forerunner to "nanotechnology". The latter is the commercial exploitation of this knowledge, at the leading edge of the field being typified by

(a) deliberative design (ie engineering) and use of materials, devices and systems that takes advantage of the properties of matter within the nano-metre range (~1-100nm); and

(b) this has been accelerated by greater convergence of knowledge spurred on by multidisciplinary research and insights.

1.6 Are there any special nanotechnology - related regulatory issues?

No there are no regulatory controls covering nanotechnology as such. Existing agencies (eg American FDA) will deal with nanotech-component product approvals. There are however some emerging societal concerns about nanotechnologies that are being addressed with guidelines in much the same way as gene-technology guidelines were put in place for biotechnology, and privacy laws as a consequence of burgeoning data storage capability. There are (highly speculative) development principles that apply to nanotechnology[10], eg. self-replication systems.

1.7 Can Australia participate in the nanotechnology revolution?

Yes! Australia is currently contributing to the many pioneering innovations in nanotechnology.

The following report provides an illustration of some of the developments in Australian nanotechnology from a cross section of disciplines and industries from both the public and private sector.

For those seeking additional general reading on nanotechnology, please refer to the examples provided in the Appendix (5a, b and c).

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9 For example the design of RelenzaTM by Biota Ltd.

10 According to the Foresight Guidelines on Molecular Nanotechnology, Original Version 1.0: February 21, 1999, Revised Draft Version 3.7: June 4, 2000, (http://www.foresight.org/guidelines)

Case Studies

2. Examples of Nanotechnology Applications in Australian industry.

Summary - This section illustrates how nanotechnology is being adopted and applied by Australian companies.

Case studies have been selected to cover diverse industry sectors.

These illustrate that the uptake of nanotechnology need not be "grand leap" in nature, but rather where nanotechnology can be used to improve existing products and processes.

Examples of "imaginings" or potential applications of the technology are provided in the subsequent section. The examples selected are typically embryonic or newly established "product concepts".

These illustrate different types of nanotechnology developments, their potential impact on industry and the work and investment required to bring them closer to realisation.

The following company cases studies (Section 2.1) have been categorised by industry sector. They do not cover all potential areas of industry in which nanotechnology might be applied. Many nanotechnologies have still to find their most fruitful area for commercial exploitation, so an example of a platform-technology company is included to illustrate an example where there are many openings for its technology. The section that follows (Section 2.2) highlights examples of illustrative product-concept nanotechnology "imaginings".

The distinction between company case studies and "imaginings" in some instances is narrow. In general, the former describe companies that have *product* offerings (encapsulating an aspect of nanotechnology) that are closer to commercialisation and market. These companies typically have intensive R&D activities, and may be connected with public sector research institutes.

Examples of *product-concept* "imaginings" are drawn from work ongoing in public sector research institutions, though typically these institutions will form, or have formed, companies as "spin-outs" or "start-up" entities to commercialise their ideas. These typically require intensive development and much investment to advance and commercialise the "imagining".

Table 3 lists the selected case studies and illustrates the cross section of companies employing nanotechnology to further develop their business. By comparison, Table 4 in Section 2.2 is an overview of product-concept "imaginings" selected as case studies. These examples show the diversity of research conducted in various universities and research institutions in Australia.

A critical capability essential to analysis, trouble-shooting and indeed fabrication of nano-scale objects eg surfaces/materials, is the ability to *visualise, fabricate and manipulate* matter at the ultra-structural or nano-scale level. A suite of complex instrumentation and microscopy is needed for such tasks. Australian capability in such *services* has been included in both Sections 2.1 and 2.2 as any national industry will require such a sophisticated service based capability. Currently, much of this capability by way of infrastructure and facilities is housed within public sector research institutions.

It is stressed that all the following examples are illustrative, and are not to be regarded as the best, or the only national capability in nanotechnology.

2.1 Australian Company Case Studies

Table 3: Australian Company Case Studies

The following table provides an overview of the company case studies included in this report. These case studies are to provide a cross section of industries that will realise the long term benefits that nanotechnology has to offer.

SECTOR	COMPANY	PRODUCTS	MAJOR ATTRIBUTE
Advanced Manufacturing	**Advanced Nano Technologies Pty Ltd**	Advanced processing technology for the manufacture of nanopowders	The ***simpler and smarter*** manufacture of nanopowders by solid-state reactions allows the production of purer nanopowders.
	Bottle Magic Pty Ltd	Superior Glass Bottle Protection Coating	The development of a ***smarter*** protection coating that has the ability to block out UV and other harmful wavelengths
	Orica/Dulux	Exploring polymer nanolattices used in unique paint applications	The development of ***smarter*** paints that are more durable with improved cleanliness attributes
Electronics, Computing and Communications	**cap - XX Pty Ltd**	Innovative Supercapacitor - High density power storage devices	Development of ***smaller and smarter*** supercapacitors that can be employed in portable computers and phones
	Bandwidth Foundry Pty Ltd	Explore and develop photonics bandgap technologies	***Smaller and smarter*** micro-photonic devices to be applied to ultra-compact lasers, the internet, optical switches and all-optical transistors
	Pro-M Technology Pty Ltd	Innovative photolithographic masking tools for photonic and semicondutor industries	Development of ***smarter*** design and prototyping of extremely small devices
Health, Therapeutics and Diagnostics	**Ambri Ltd**	Innovative biosensor used as a diagnostic tool	***Faster, simpler and smarter*** diagnostic tool to be used immediately in emergency wards and replaces centralised pathology testing
	The Starpharma Group Ltd	Novel pharmaceutical application of polycovalent dendrimer nanotechnology	***Smarter and faster*** drugs against STD, cancer and respiratory disease
Platform Technologies, Multiple Industrial Applications and Uses	**Dendritic Nanotechnologies Ltd**	Original Platform Dendrimer Technology	Unique structural entity boasts a wide range of ***smarter*** applications, including health, optical, electrical and chemical implementations
	Quantum Precision Instruments Pty Ltd	Novel Micro-Electro Mechanical System Devices to be used in the development of Nanotechnology applications	***Smarter, cheaper and easier*** to use devices that can precisely measure to the level of a nanometre.

Advanced Nano Technologies Pty Ltd

What is the business?

Advanced Nano Technologies Pty Ltd ("ANT") is an advanced materials company established in April 2000, to commercialise its patented mechanochemical nanopowder processing (MCP™) technology. ANT is a joint venture, between Samsung Corning, a Korean based world-leader in electronic materials, and Advanced Powder Technology Pty Ltd, a spin-off company of the University of Western Australia ("UWA"), where the technology was developed.

The initial joint venture funding has been used to build a pilot plant in Western Australia, which allows ANT to make commercial scale samples of a wide range of metallic, ceramic and semiconductor nanopowders. ANT has since received further funding of $2.8 Million through the Commonwealth Government R&D Start Grant program, which has allowed ANT to concentrate on further optimising the use of their nano particles in downstream applications.

Why are they interested in Nanotechnology?

Nanopowders, which consist of particles less than 100nm in size, form the basis for a wide range of new nanomaterials, specifically engineered to exhibit enhanced chemical, mechanical, optical, biological and/or electromagnetic properties. Nanomaterials are being exploited over a wide spectrum of new and exciting industry applications. The first nanomaterials property to be exploited is the transparency of nanopowders, which allows the functional attributes of oxides to be exploited in transparent applications.

Through the patented MCP™ technology, ANT can provide a wide range of nanopowders that are uniquely engineered for a particular size, shape and/or surface coating.

For example,

How does it work? Why is it Nanotechnology?

ANT differentiate themselves from other nanopowder manufacturers by their patented MCP™ technology. The MCP™ technology is different to existing nanopowder production processes, as the nanopowders are formed by a solid state reaction, which allows excellent control of the particle size, size distribution and agglomeration. Controlling these three factors is critical to the performance of nanomaterials as larger particles and/or agglomerates are detrimental to performance.

The MCP™ technology is an efficient and low cost manufacturing method, relying on the use of industrially standard precursors and equipment. ANT manufactures nanopowders by exploiting mechanical and chemical reactions in a standard ball mill. The MCP™ technology produces the nanopowders in a solid salt phase which allows the particles to be further treated to stabilise or change the shape of the particles. This solid diluent phase can be easily removed to produce high quality, non-agglomerated nanopowders that have been specifically tailored to customers needs.

What are the benefits?

MCP™ technology offers a wide range of benefits that are of a distinct advantage over other nanopowder manufacturing processes.

Improved Nanopowder Quality: In comparison to other manufacturing processors, the MCP™ technology produces "true" nanopowders with a smaller size, narrower size distribution and minimal agglomeration. Competing processes generally use either a vapour or liquid phase to produce their particles, which makes it much harder to

MCP™ Nanopowder	Ideal Application	Size (nm)
MCP Ceria	CMP Slurries, Auto Catalysts, Fuel Cells,	5, 25, 40
MCP Zinc Oxide	Transparent UV absorbing Applications, Anti-bacterial Function	25, 80
MCP Zirconia	Catalysts and Structural Ceramics	5, 25
ZinClear™	A Hydrophobic form of 25nm ZnO, pre-dispersed in various oils for use in Sunscreens	25

control these attributes, and typically result in agglomerated, "nanostructured" or "nanocrystalline" powders.

Simplicity: The MCP™ technology provides a simple alternative to producing nanopowders compared with other processes which employ high temperatures or complex chemical reactions. The lower temperatures and shorter milling times, allow MCP™ technology to achieve high production rates, with concomitant lower production costs.

Flexibility: MCP™ technology gives greater flexibility in the choice of raw materials used to generate the nanopowders and therefore provides the opportunity to use lower costing and more readily available precursors. Furthermore, the technology permits a greater level of control of the development of nanopowders; it gives flexibility to the shape, size and purity of the powder, which therefore can be specifically tailored to the customers needs. These unique characteristics produce a variety of novel nanopowders that can be employed in a wide range of exciting applications.

Where is the product headed?

ANT has signed its first licence agreement of the patented MCP™ technology with Samsung Corning. The production of the cerium oxide nanopowder slurries is a critical step in the manufacture of computer chips. It is expected that these high value polishing nanopowders based on MCP™ technology will be an integral part of the manufacture of the next generation VLSI chip. Samsung Corning predicts that the production of the cerium oxide nanopowder to commercially commence in 2003 and has targeted sales to be USD$23 million in 2005.

ANT recently launched ZinClear™ on the international cosmetics market and is currently working with many Australian and international cosmetic formulators to develop new products. ZinClear is a transparent form of zinc oxide, the commonly used UV absorber. ZnO is a preferred UV absorber due to its hypoallergenic nature, lack of absorption in to the skin, and broad spectrum UV absorption profile. ZinClear's transparent nature allows formulators to decrease the loading of chemical absorbers, whilst, at the same time, not increasing the whiting effect on the skin.

Who are they working with?

ANT has had enquiries for it's nanopowders from more than 100 different companies world wide. ANT is currently working, under the protection of Non-disclosure Agreements, with the research departments of many leading multinationals involved in the microelectronics, cosmetics and plastics industries.

Company Contacts

Dr Paul McCormick
CEO
Advanced Nano Technologies Pty Ltd
112 Radium Street
Welshpool, WA 6106
Phone 08 9380 3122

Bottle Magic Australia Pty Ltd

What is the business?

Bottle Magic Australia Pty Ltd ("Bottle Magic") are glass bottle decorators who differentiate themselves by creating unique packaging opportunities. Bottle Magic have been providing new glass bottle coating technologies, which enable glass bottles to be coated in a vast range of colours in several different types of finishes. The endless variety of colours and finishes allows for the unprecedented freedom in design and creation of novel packaging.

The new venture commenced commercial production in September 1998 with its colouring technology and commenced researching UV protection coatings the following year.

Why are they interested in Nanotechnology?

Bottle Magic aims to not only provide a wide range of innovative bottle coatings but also to produce coatings that are functional beyond visual aesthetics. Since 1999 Bottle Magic has worked closely in conjunction with CSIRO Manufacturing Science and Technology to create a Premium Product Protection solution. This technology has the ability to block out UV and critical visible light wavelengths that have deleterious effects upon the packaged food or beverage.

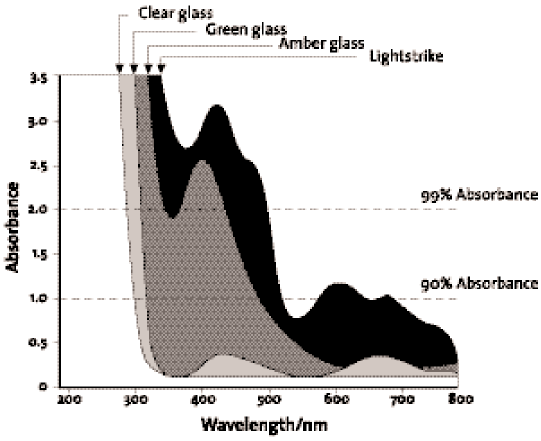
How does this work? Why is it Nanotechnology?

The patented technology is based on a coating composition that includes a carrier and a pigment dispersed in the carrier. The pigment includes nanoparticles of a UV and visible light absorber. The nanoparticles are small enough to appear transparent with no haze in visible light when added to a transparent coloured coating.

What are the benefits/attributes of the technology?

The novel coating formulation provides a number of benefits in comparison with conventional clear glass or green bottle. The coating has the innovative ability to block out harmful wavelengths and UV light that are detrimental to the packaged foods and beverages such as beer, wine, champagne, olive oil and other foods. This coating technology can:

- extend shelf life;
- preserve product quality; and
- improve long term quality.



The graph shows that Bottlemagic's new coating technology dramatically improves the UV absorbance of green glass.

Another positive attribute of the new process is that it does not affect the environmentally benign status of glass as a packaging medium. The coating on the glass product does not interfere with current recycling programs. The coating applied via the nanotechnology is designed to be removed in the glass-melting phase of the recycling process.

Where is the product headed?

Bottle Magic was awarded the 1999 Australian Packaging Innovation Award.

This new technology is at an early stage of commercialisation with sound expectations of securing significant international markets.

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Orica Australia Pty Ltd

What is the business?

Orica Australia Pty Ltd was created following the separation from ICI plc. in 1997. One significant outcome of this division was the amalgamation of all of the Dulux businesses together with Cabots and Selleys to create a powerful consumer orientated business with sales of over $600M. The decision to concentrate on consumer products was finalised by the sales of the more industrially based Dulux businesses, such as automotive, in 1998.

The value of an in-house R&D organisation was recognised very early as an essential element in the management and gradual improvement of increasingly sophisticated paint technologies. The commitment to R&D is substantial with a total of seventy full time technical staff and a budget of over $8M per annum.

Why are they interested in Nanotechnology?

The paint industry is moving to waterborne materials, the process only being slowed by the few performance attributes where solvent borne materials win out. The cleansability attributes of solvent borne materials are still highly regarded by the consumer for the more demanding end uses requiring hardness, toughness and scuff resistance.

The majority of water borne coatings and adhesives are formulated using polymer latices or dispersions, tiny polymeric particles which come together as water evaporates and fuse to become a paint film. Smaller polymer particles are useful in that they fuse to become dense well integrated films better able to stand up to harsh treatment exemplified by resistance to common household stains.

However, there are also constraints in driving the polymer particles to smaller and smaller size. Performance may be compromised by issues of mechanical stability and ease of use, such as being able to accommodate the wide range of concentrated colourants required for in-store tinting

In its patented Wash & Wear 101 development, Dulux researchers have made use of specially formulated polymer latices where the average size of the particles is well below 100nm. A family of latex technology has been developed tailored to deliver specific performance outcomes for gloss as well as flat interior coatings. Particle size control, the method of achieving stability and blends of particles with different compositions and surface groups are all features of the technology.

How does it work? Why is it Nanotechnology?

The benefits of Wash & Wear 101 development specifically exploit emulsion polymerisation nanotechnology. These developments concern the manner in which the molecular building blocks come together to form the final polymer particle.

Dulux have differentiated themselves from suppliers of commodity latex technology to the paint industry in the way they have developed innovative concepts in the science of emulsion polymerisation to produce a new product capable of targeting very specific balance of coating properties.

At one extreme the science is concerned with maximising the stability of particles as they form. In this area Dulux have patented a new process with novel stabiliser molecules designed to participate in the chemical reactions that drive particle formation. The result is hyper-stable particles easily able to accommodate the stresses imposed by the addition of high levels of tinter, and mechanical shear.

At another extreme, the technology is concerned with the combination of polymer particles with controlled composition. It is not enough to allow the statistics of an industrial polymerisation process to deliver coarse 'average' compositions but more designer particles where the internal composition is crafted to deliver precision – compositions where the surface area of the polymer particles present just the right amount of the key ingredients to the rest of the paint system.

What are the benefits/attributes of the technology?

The Dulux 101 technology has great flexibility. Different features of the technology can be harnessed to deliver performance requirements which are biased towards the type of coating and its use. Gloss coatings are at one extreme; they are composed of high levels of polymer latex and relatively little reinforcing pigment or filler. In this case, the latex must deliver hardness to compensate for the absence of filler. For a flat coating, adequate binding of high levels of pigment and filler is the over riding issue.

In the laboratory the research is continuing. Even more improvement is possible by delving deeper into the interior of polymeric latex particles and studying the molecular processes that control their formation

Where is the product headed?

There is no doubt that the Dulux 101 development has been very well received by the Australian marketpace. Consumers have embraced the product and appreciated the delivery of improved stain resistance as an important feature of interior coating performance.

The Dulux 101 development is not the end of the story. The separation from ICI has given Dulux the freedom to decide on its future growth strategy with the global marketplace open to it. The 101 story has attracted the attention of major multinational raw material suppliers to the paint industry as well as international paint companies. The message of improved cleansability is universal for paint consumers. All that remains is for another enterprising marketing based company to pick up the package and run with it.

Who are they working with?

Wash & Wear 101 is a technical development by the Dulux research team and is currently enjoying market success. However, the world is a big place. All that remains is for the Dulux commercial team to find other consumers and partners who want to emulate the success.

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cap-XX Pty Ltd

What is the business?

cap-XX Pty Ltd ("cap-XX") is an Australian company that was incorporated in 1997, and focuses on developing and commercialising advanced supercapacitors - high power energy storage devices. Supercapacitors can be used in a variety of industries as diverse as telecommunications, computer, power quality and automotive applications. In the short-term cap-XX is targeting wireless communication and notebook computer applications. The technology underlying the supercapacitors was initially developed in a joint project conducted by Plessey Components Pty Ltd and CSIRO that commenced in 1994. The research and development work was accelerated after cap-XX was registered as a company. cap-XX has received both New South Wales and Commonwealth Government funding (including two AusIndustry R&D Start Grants) to help commercialise the technology. They currently have approximately 20 pending primary patents in relation to their innovative energy storage device

Why are they interested in Nanotechnology?

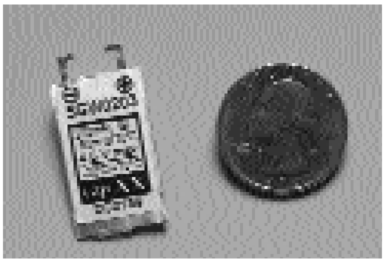
The performance of supercapacitors is dictated by nano-structured materials and nano-scale processes. Most consumers want a better mobile experience-devices that are smaller, more portable and more highly functional. The best way to achieve this outcome for consumers is to understand and utilize the colloid and surface chemistry, electrochemistry, material science and condensed matter physics that govern the application of nanotechnology in energy storage devices.

How does it work? Why is it Nanotechnology?

In capacitors, the phenomena of energy storage occurs when two parallel plates are connected to an external circuit and a voltage is applied. cap-XX supercapacitors work by employing a nano-structured colloidal carbon electrode material with an extremely large surface area (greater than 1000 m^2 per gram) and by taking advantage of the electrical double layer that forms at the interface between an electrode and an electrolyte in all electrochemical systems. An applied potential controlled, reversible nano-scale ion adsorption/desorption process results in the rapid charging/discharging (high power) capability for supercapacitors. This process takes place predominantly inside the meso-(nano-)pores of the carbon. In essence, the charge (energy) is stored by way of layers of ions (less than a nanometre in width) inside pores that are on average less than two nanometers in diameter.

What are the benefits/attributes of the technology?

Energy storage devices can be broadly classified by their energy density (energy stored per unit of mass) or their power density (how fast the energy can be delivered). At one end of the spectrum conventional capacitors can deliver enormous power but store only small amounts of energy. In comparison, batteries store a high level of energy but have low power and take a long time to discharge their energy. Supercapacitors are unique in that they bridge the energy storage and power delivery capabilities of batteries and conventional capacitors. In recent years there have been major advances in the design of low impedance (low resistance) supercapacitors, which are ideally suited for high power applications for mobile devices, particularly those using GSM (Global System for Mobile communication) and GPRS (General Packet Radio Service) wireless technologies. Supercapacitors are power sources that can be used in combination with batteries to minimise the damaging effects of high current pulses. The supercapacitor can supply the peak loads of energy, whereas the more constant energy requirements can be sourced from the battery. This synergistic relationship better utilises energy resources and may also extend the lifetime of the batteries. Power management technologies, like cap-XX's, are also important for the computing industry.



Supercapacitor, designed for digital wireless communication device. A U.S. quarter is also shown to provide relative size comparison.

Where is the product headed?

Currently cap-XX employs 40 employees but expects this head count to significantly increase in the near future as a result of up coming events. High volume production lines are being installed in Sydney this year. As a result of their leading technology and high quality product, cap-XX is expected to dominate the supercapacitor market, which some forecasters predict will eventually exceed USD6 billion. cap-XX is expanding globally and has sales staff based in the US and Taiwan .

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Bandwidth Foundry Pty Ltd

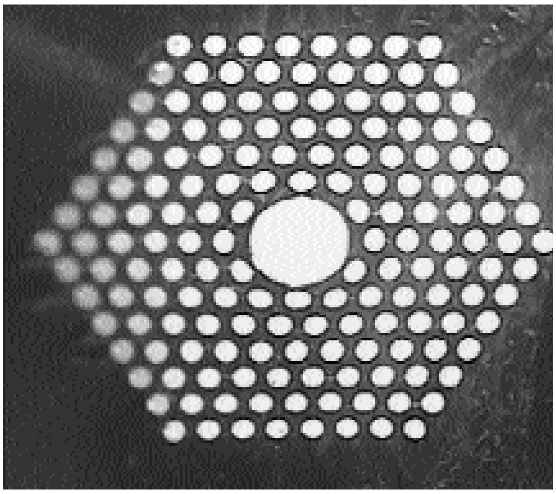
What is the business?

The Bandwidth Foundry - incorporated in January 2002 - has been given the mandate to explore and develop photonics bandgap (PBG) technologies for novel telecommunication and sensing applications.

Why are they interested in nanotechnology?

The 90's were marked by the rapid development of PBG technologies with promises of novel photonics devices in conjunction with hundred-fold size reduction over conventional photonics devices. Several groups have developed PBG devices where light guidance is achieved not by the conventional total internal reflection but rather by the existence of forbidden wavelength (or colour) "gaps" created in the bulk material by the presence of periodic nanostructures (thus analogous to semiconductor properties).

A precise control over these periodic nanostructures - more specifically over the defects present within these structures - is key to this new generation of devices. Several methods to "write" or create these structures have been investigated worldwide e.g. using deep etching in conjunction with standard photolithography or self-assembly of nanoparticles.



Photonic Bandgap Fibre: Optical micrograph of the cross-section of a microstructured polymer optical fibre (MPOF) fabricated recently at the Optical Fibre Technology Centre (OFTC, Univ. of Sydney), a key research group within the Australian Photonics CRC. Courtesy of the OFTC.

How does it work? Why is it nanotechnology?

The general idea is that light in certain engineered PBG materials can flow in a way similar to electrical currents in semiconductor chips. It is for visible and near-infrared frequencies that PBG materials are likely to have their most important impact.

To fully appreciate the challenge of fabricating these structures, we note that the size of the basic unit cell of the photonic bandgap device must be comparable to the wavelength of the light. For the telecommunications industry, where the usual operating frequency is around 1.5 μm (in the infrared), the feature size must be on the order of 500 nm. The fabrication of these intricate structures requires state-of-the-art microlithography techniques.

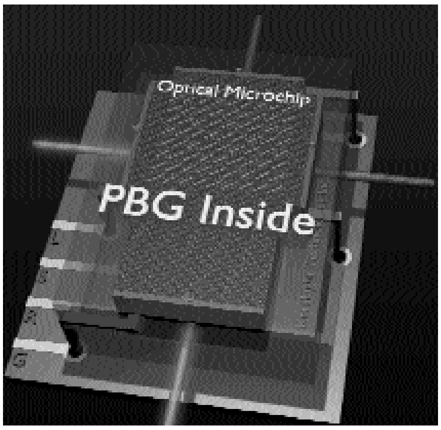
Recent advances in nanotechnology have allowed the realization and controlled engineering of PBG structures with these properties. In a parallel development, the theoretical description has matured to provide predictive tools for the design of PBG devices.

What are the benefits/attributes of the technology?

PBG microstructures represent a new frontier in the field of optics, providing foundation for novel micro-photonic devices and avenues for tighter integration of these devices into a photonic chip. The applications include ultra-compact lasers, all-optical switching fabrics for routing data along the Internet, optical switches with an on-off cycle time of less than a trillionth of a second, and all-optical transistors.

The Australian Photonics CRC's view of the photonics device market is that the next generation of photonics devices will be of hybrid nature i.e. combining current photonics technology with PBG elements on a given optical microchip.

The state of PBG research suggests that this field is at a stage comparable to the early years of semiconductor technology shortly before the invention of the solid-state electronic transistor. If this analogy continues to hold, one may find PBG materials at the heart of a 21st century revolution in optical information technology similar to the revolution in electronics we have witnessed over the latter half of the 20th century.



Tunable optical microchip: Artist's depiction of an electro-actively tunable PBG routing device. Encyclopedia of Science and Technology, 2001

Where is the product headed?

The Bandwidth Foundry is developing the photolithography technology that enables PBG devices to be built upon standard integrated optics substrates. The first PBG devices are expected within the next two years.

Who are they working with?

The Bandwidth Foundry is a Major National Research Facility of the Australian Photonics CRC. The Bandwidth Foundry is currently putting in place a partnering program targeting the photonics industry.

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Pro-M Technology Pty Ltd

What is the business?

Pro-M Technology Pty Ltd has been established to provide mask and product design services, distribute a range of innovative photolithographic masking products and provide electron beam lithography (EBL) written device fabrication with the micro-electro mechanical systems ("MEMS")/Nanotechnology sphere. The market for the products will be primarily within the Semiconductor and Photonics industries.

The objectives of Pro-M Technology Pty Ltd are to provide a unique service designed to accelerate the development of leading technology industries. This will be achieved by taking a two stage approach to product introduction. This is summarised by:

1. The standard range of Photomasks and Phasemasks are well understood and known technologies, therefore seen as low risk and will offer the company significant revenue opportunity.
2. The programmable masking solution provides a higher risk opportunity in terms of development and product launch. However, the potential revenue returns are extremely significant and the product will provide the basis for the next generation of masking technology for the semiconductor industry on a global basis.

Why are they interested in Nanotechnology?

Within Australia there is no commercial facility which manufactures standard photo masking products. The current demand in Australia is satisfied from either small university facilities using inadequate old technology or on a high cost, long turnaround time commercial basis from overseas suppliers.

Currently there are no readily available design and prototyping services for start-up companies, universities or private inventors in Australia, particularly for electron beam writing of very small geometry devices typically termed nanotechnology. Expertise within Australia is limited and dispersed within the engineering and scientific community.

The programmable masking plate and quantum precision alignment system have not been developed by any company, globally. It will be these products which will make Pro - M Technology unique on a global scale within the photomask industry.

How does it work? Why is it Nanotechnology?

An important consideration for Pro-M Technology will be to ensure the product is targeting the key deep-submicron to nanometre minimum feature size technology. This particular aspect of photomasks is one which is under continual development within the industry and one in which the key players strive to minimise in order to satisfy the ever growing demand from the nanotechnology industry sector. The reason for this is that the industry roadmaps for semiconductor devices are driving device sizes smaller and smaller. The technology roadmaps within the photomask industry are being driven by the requirements of the chip manufacturers. In order to maintain a competitive technology advantage over the chip manufacturers, the photomask industry is striving to foresee the technology roadmaps of the chip producers in advance.

What are the benefits/attributes of the technology?

Whilst the standard range of photomask products Pro - M technology offers will compare on a similar scale with other mask producers, Pro-M Technology will be able to provide strong services to clientele. Within Australia, mask fabrication is a rapidly growing market that has previously been under-developed and under serviced by commercial operations outside of Australia. Prototyping of devices using electron beam writing is unavailable to the majority of customers within Australia. Existing facilities are currently dedicated to a very small percentage of possible customers and are often unable to meet their own requirements. Therefore, a facility to provide prototyping services, as well as mask design and fabrication will be of great benefit to the development of nanotechnologies within Australia.

Where is the product headed?

The competitive edge of Pro-M Technology is envisioned to be the electronically programmable mask linked to the quantum precision alignment system. This particular product will be totally unique within what is a US$5 billion per year industry on a global basis. We will be able to offer customers a flexibility in their product otherwise unavailable with a standard photomask. It is this increased flexibility that will be invaluable to mask users and research organisations alike.

Currently, the industry standard for layer-to-layer alignment registration using industry optical alignment systems is limited to tens of nanometres. As dimensions continue to shrink, alignment issues will emerge as a key limiting factor for future development of the devices. The quantum precision alignment system will enable systems to automatically register layer-to-layer alignment on the Angstrom scale. Our system, when coupled with the electronically programmable mask, has the capacity to revolutionise today's leading edge technologies. It will be these products and services that will have the potential to place Pro-M Technology Pty Ltd as a global force within the industry.

Who are they working with?

Currently Pro - M Technology has developed close alliances with key partners within Australia and within the UK in order to develop the products, in particular the programmable masking solution. The development of the business is supported by a dedicated and highly experienced management team and board of directors.

Company Contact Details:

The company is headquartered in Sydney, Australia with an office soon to open in Cambridge, UK.

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Ambri Ltd

What is the business?

Ambri Limited ("Ambri") is commercialising a novel biosensor, the AMBRI™ Technology, into a Point of Care system which is intended to be used in the Critical Care segment of the time critical pathology testing market. The AMBRI™ Technology is a result of extensive, collaborative research and development undertaken from 1988 to 1999 by Ambri and the Co-operative Research Centre for Molecular Engineering and Technology (CRC). Other participants in the CRC were the CSIRO and the University of Sydney. Substantial funding for the developmental work was obtained from the Commonwealth Government through GIRD and CRC Grants. Ambri, originally a wholly owned subsidiary of Pacific Dunlop, listed on the ASX on 23rd August 2001. The intellectual property associated with the AMBRI™ Technology was acquired by Ambri in 2001.

Why are they interested in Nanotechnology?

The Point of Care System comprises the Ambri SensiDx™ reader and an associated series of test-specific single-use disposables which read the concentration of specified markers in whole blood with no added reagents and no sample preparation. It is intended to provide a compact pathology testing tool to allow Critical Care Physicians to obtain reliable and accurate results within 3 - 5 minutes, equivalent in quality to the traditional central laboratory tests which take 4 - 24 hours to obtain.

How does it work? Why is it Nanotechnology?

The AMBRI™ Technology is a unique nanotechnology biosensor that mimics ion channel based signalling in biology. It is a purpose built device that depends for its function on a nanometre scale molecular construct that enables the detection of elements, molecules and molecular assemblies including ions such as potassium and sodium; small drugs such as digoxin, thyroxin and theophylline; large proteins such as TSH, Ferritin and hCG; oligonucleotides and DNA sequences; and micro-organisms such as *E coli* and *B subtilis*.

Like cell membranes found in all mammalian nerve cells, the AMBRITM biosensor is composed of a synthetic tethered membrane and incorporated ionophores, or ion channels. The membrane is tethered to a gold coated surface using a sulphur chemistry and is separated from the surface by a 4nm thick polar layer which provides a reservoir into which ions may flow when they have traversed the membrane.

To measure the concentration of an electrolyte such as potassium, an ionophore, in this case valinomycin, is incorporated into the membrane making it selectively permeable to potassium. As the potassium concentration varies ions pass from the bulk solution through the membrane and into the reservoir space causing the electrical conductance of the membrane to vary proportionately to the potassium concentration. Ranges of different ionophores are employed to produce a range of different membranes, each selectively permeable to a particular ion.

To measure the concentration of proteins or microorganisms in a sample the ion channel gramicidin is incorporated into the membrane. These channels allow the transport of sodium ions through the membrane. The gramicidin channels are covalently attached to antibody fragments, which have been chosen to specifically recognise and bind to particular molecular targets, which is the subject of the assay. Binding of the target molecule causes the two halves of the gramicidin channel to become misaligned, breaking the conduction path for ions across the membrane. This event is read as a change in electrical conductance. Measuring the rate at which the ion channels are turned off provides a quantitative measurement of the concentration of the target species in the sample. A similar scheme is employed for determining the concentration of a drug or other low molecular weight compound.

What are the benefits?

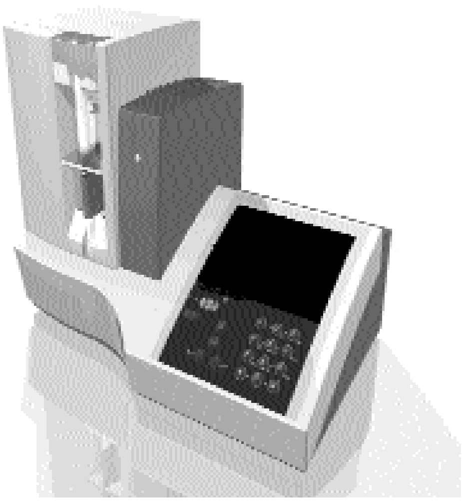
During 1999 there were approximately 103.7 million visits to the emergency departments across the USA. Each visit resulted in on average 9.4 tests. Despite the high number and the urgency of the emergency visit, the majority of Critical Care Unit Pathology Testing is still performed by Central Laboratory systems. Ambri believes that the development of the SensiDx™ System will help advance Point of Care Testing in Critical Care and expedite the capability of immediate diagnostic testing in the emergency department, at an accident scene, in an operating theatre or in the intensive care unit.

Point of Care Testing has significant advantages over Centralised Laboratory Testing, in particular increasing time efficiency and reducing associated pathological testing costs.

Where is the product headed?

Ambri plans to launch the SensiDx™ System, pictured below, into the Australian market in the third quarter of 2002 and into the US in the first quarter 2003.

The global Point of Care Testing market is forecast to grow to $7 billion by 2008. Currently there is no single player that has established market dominance in this sector. Ambri anticipates becoming a major global stakeholder in the Point of Care Testing sector.



SensiDx ™ System

Many other potential applications exist for the technology. These will be pursued through both licensing and through partnerships. Examples of other potential applications include:

- Rapid testing of food, wine and beverages
- Military defence applications for the detection of chemical and biological weapons
- Point of care veterinary
- Measurement of environmental pollutants

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Starpharma Pooled Development Ltd

What is the business?

Starpharma Pooled Development Limited (ASX: SPL; "Starpharma") is the parent funding entity of a publicly listed research and development group. Starpharma was established in 1996 to develop and commercialise a polyvalent technology, or dendrimers, as pharmaceuticals under an exclusive worldwide licence to intellectual property developed since 1992 from the Biomolecular Research Institute in Melbourne.

Starpharma is a Pooled Development Fund (PDF) that funds three wholly-owned subsidiary companies and has a significant shareholding in a fourth company, Dendritic Nanotechnologies Limited (DNT) based in Michigan. A PDF is an Australian Commonwealth Government initiative designed to encourage the investment of patient equity capital for growing small to medium size enterprises by conferring specific tax benefits to the PDF investors. The group has continued to raise capital successfully through a public float on the Australian Stock Exchange in September 2000, and by attracting federal funding in the form of two R&D Start grants.

Starpharma is applying leading edge nanotechnology techniques in the creation of dendritic nanodrugs to address major global health needs. Starpharma's strategy using dendrimer compounds is to:

- discover new drug opportunities;
- generate and protect intellectual property;
- develop illustrative lead compounds to the stage of Phase II human clinical trials prior to licensing to a pharmaceutical company;
- seek earlier licensing opportunities for promising compounds in non-core areas.

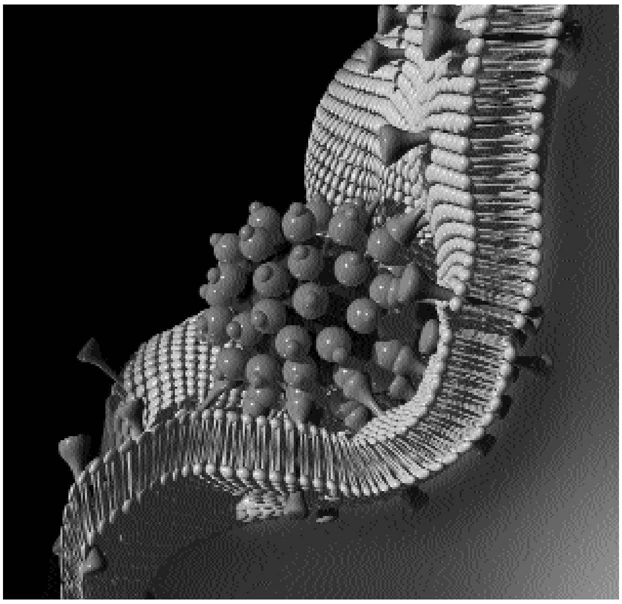
Why are they interested in nanotechnology?

Applications of dendrimers in the pharmaceutical field offer revolutionary opportunities. Starpharma focuses on the development of dendrimers to act as pharmaceutical agents. This functionality is achieved by the attachment of pharmaceutically active chemical groups to dendrimer compounds. Dendrimers can also act as an effective drug delivery vehicle to carry existing drugs to their target. Starpharma's priority disease targets are:

- viral sexually transmitted diseases (STDs), including HIV, genital herpes, hepatitis B, genital warts and Chlamydia;
- tumour-related cancers;
- toxin-related illnesses;
- respiratory diseases.

Currently, Starpharma's core product development focus is on the prevention and treatment of sexually transmitted diseases. Starpharma's lead product, which is in the preclinical development stage, is a topical vaginal microbicide gel to prevent transmission of STDs such as HIV, genital herpes, hepatitis B, genital warts and Chlamydia.

Dendrimers have other applications in the biotechnology field as diagnostic tools and as vehicles for transfection of genetic material into cells.



Dendrimers are capable of polyvalent, or multiple-site, interactions with biological receptors and binding sites.

How does it work? Why is it nanotechnology?

Dendritic compounds are a unique class of synthetic, three-dimensional nanostructure that allow for precise control over their size, shape and functionality. Dendrimers are built by repetitive addition of branching groups around a single core molecule, resulting in the formation of a chemical scaffold. Dendrimers are built in successive generations, and commonly have dimensions of 3, 4 or 5 nanometres, similar in size to small biological proteins, but can be much larger. Chemical capping groups placed on the chemical scaffold may be chosen to have, for example, pharmaceutical activity. However, dendrimers may be used as macromolecular platforms suitable for a wide range of applications in nanotechnology (for other applications, see Dendritic Nanotechnologies Limited case study).

What are the benefits?

Dendrimer molecules can act as a platform to which a variety of therapeutic or other molecules can be attached. Therefore, dendrimers as pharmaceuticals have been shown to have a broad spectrum of activity against a wide range of diseases, are able to be targeted to treat a particular disease, and are modifiable for specific tissue targeting and improved bioavailability. Importantly, dendrimers have low toxicity and antigenicity, which may allow for safe and repeated use in humans. Dendrimers as pharmaceuticals are much larger than conventional, small molecule pharmaceuticals, and are capable of polyvalent, or multiple-site, interactions with biological receptors or binding sites. This type of interaction compares favourably with conventional drugs that are usually capable of only monovalent, or single-site, interactions.

Where is the product headed?

Sexual health, particularly for women, is a major problem worldwide, with more than 15 million people in the US alone set to acquire a new STD each year. Globally, the AIDS epidemic is growing and decimating many developing communities. Approximately 40 million people, many of them women and children, are living with HIV/AIDS infection. Everyday, about 14,000 new infections occur. Since the beginning of the HIV/AIDS epidemic, almost 30 million people have died from AIDS. Until now, most HIV/AIDS drug development programs have targeted treatment of the disease. There are currently no effective topical microbicides on the market that are able to prevent HIV infection in women.

Starpharma's lead product, which targets the prevention of STD infection in women, is set to become the first dendrimer-based nanodrug to be tested in human clinical trials. Financial support for the development of this product is being provided by institutions such as the US National Institutes of Health (NIH).

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Dendritic Nanotechnologies Ltd

What is the business?

Dendritic Nanotechnologies Ltd's (DNT) strategy is to maximise the value of the dendrimer technology platform by creating and protecting intellectual property, and partnering with industry leaders, across a broad range of sectors, in order to facilitate the incorporation of dendrimers into systems and products. DNT is an international venture between a nanotechnology pioneer in the US, Dr. Donald Tomalia, Central Michigan University and the Australian company Starpharma Pooled Development Limited (Starpharma). Starpharma specialises in the development of polyvalent dendrimer structures as novel pharmaceutical agents. DNT's primary office and research facilities are located at the Center for Applied Research & Technology at Central Michigan University, Mt Pleasant, Michigan, USA.

Why are they interested in nanotechnology?

The high potential value of dendrimers lies in the depth and diversity of their potential applications. These include biopharmaceutical, diagnostic and gene therapy uses, roles in optical and electronic nanotechnology, and application in a wide range of both basic and applied chemical uses.

How does it work? Why is it nanotechnology?

Dendrimers are a novel class of precise, three-dimensional, nanoscale compound that can be modified for a wide range of applications. Building on a core central molecule, dendrimers are formed through step-wise, sequential addition of symmetrical branched molecules and connector groups. Each branched molecule-connector group layer is referred to as a dendritic generation, up to ten of which can be incorporated into a single dendrimer molecule.

As a result of their unique structure and synthesis process, dendrimers possess a number of remarkable inherent physical, chemical and biological properties. These include:

- *Precise architecture and size control* - Dendrimers branch out predictably to form three-dimensional structures with highly ordered architectures. Precise control over size and architecture is essential for determining and manipulating the properties and applications of nanomaterials, allowing the design and synthesis of nanoscale objects and devices to a high degree of accuracy.
- *High uniformity and purity* - A high degree of uniformity is again essential to a reproducible, precise manipulation of the physical properties of nanoscale objects. High purity is also essential to obtaining regulatory approval for the use of any nanotechnology in life sciences applications.
- *High loading capacity* - Internal cavities in the dendrimer structure can be applied to carry and store a wide range of organic and inorganic molecules, which provides the opportunity to tailor dendrimers for the delivery of materials such as drugs, diagnostics, cosmetics and agricultural agents.
- *High physical strength and stability* - Through their three-dimensional, inter-linked structure, dendrimers have a significantly higher resistance to shear forces and solution conditions. This physical strength and stability allows dendrimers to act as chemical additives in a wide range of scenarios, including many in which traditional polymer materials are inapplicable.
- *Low toxicity and immunogenicity* - Dendrimers have been shown to elicit a very low toxicity and negligible immunogenic response, which is highly desirable for use of compounds in biological systems.

What are the benefits?

Dendrimer nanotechnology offers a wide range of potential applications. The following are some examples (for pharmaceutical applications - see Starpharma Pooled Development Limited case study):

1) Nano-optical and nano-electronic applications:

i) ***Optical:*** Dendrimers potentially can be applied to several optical applications including optical nanoparticles, optical amplifiers and in the development of high-powered lasers. For example, if light harvesting optical molecules are incorporated throughout the internal scaffold and a single photoactive molecule is placed at the core, multi-frequency light can be converted to single frequency light. This conversion results in amplification of the light energy, which can be precisely controlled by the design and the size of the dendrimer. Such unique properties will have promising applications in the development of new laser devices.

ii) ***Electronic:*** Dendrimers may act as advanced nanoelectronic materials in their own right or may act as a template for the precise manufacture of nanoelectronic components. Dendrimers have remarkable potential to store data in binary form when appropriate metal species are incorporated in the interior and the number and location of each atom can be manipulated via appropriate activation mechanisms, such as electronic excitation level and oxidation states. Further modification of the chemical groups in the dendrimer is believed to transform the nanoparticles into tiny, and therefore more efficient, electrical conductors.

2) Chemical applications:

i) ***Applied:*** By altering outer active capping groups, dendrimers can be chemically modified to act in different ways in various chemical reactions. Dendrimers could be given catalytic, chemical sensing, sequestering or additive properties, or be used as calibration agents.

ii) ***Basic:*** Tightly packed clusters or assemblies of dendrimers can be built when, for example, an active nanoscale agent is required on the micrometre scale. Dendrimers may serve to act as a template for manufacturing materials of precise size and shape characteristics. Spherical dendrimer assemblies could be used as spherical particles of precise and highly uniform size, allowing for example, the formation of very high quality advanced ceramic components.

Where is the product headed?

DNT has established production capabilities at the Centre for Applied Research and Technology, Central Michigan University, Mt Pleasant, Michigan, USA. The laboratory and manufacturing facility will supply a broad range of high quality dendrimers up to 1 kg in quantity. DNT has already secured significant orders from chemical and biotechnology companies for the design and manufacture of high quality dendrimers. DNT is also undertaking business development initiatives with a number of major corporations to secure Collaboration Programs for the development and commercialisation of dendrimers.

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Quantum Precision Instruments Pty Ltd

What is the business?

Quantum Precision Instruments Pty Ltd ("QPI") was founded by Dr Marek T. Michalewicz in July 1999. QPI is developing and plans to build atomic precision positioning metrology devices for microelectronics and sensors that will be used in medicine, bio-technology, aviation, defence, automotive, seismic, mining and other industries. All these devices are based on QPI's own patented technology. Dr Michalewicz, QPI's Managing Director and the inventor of the technology, is a physicist with expertise in computational and quantum physics, chemistry, materials science and computational life sciences, supercomputing and nanotechnology. He was previously a Principal Research Scientist at the CSIRO Mathematical and Information Sciences High Performance Computing Support Group

Why are they interested in Nanotechnology?

QPI devices belong to a family of micro-electro mechanical systems ("MEMS"). They will serve in extremely precise lithographic mask alignment in microelectronics industry and other instrumentation. This family of devices, called nanoTrek^{TM}, are extremely precise instruments capable of billionth of a metre position and thousandth of a degree angular measurement. This provides the capability to position, measure, rotate, align and translate nanostructures and nanoparticles in a static regime. In a dynamic regime, these devices are capable of measuring flow, frequency, acceleration, and vibration. Measuring these parameters is mandatory for maintaining extremely high levels of precision and accuracy demanded when manipulating on the level of the nanometre. Therefore QPI hopes to take advantage of the significant increase in the need for these instruments with the concomitant increase in momentum and activity in the nanotechnology spectrum.

How does it work? Why is it Nanotechnology?

nanoTrek^{TM} devices are based on the principle of quantum tunnelling. Tunnelling of particles (electrons, protons, alpha particles) is an exclusively quantum phenomenon which can only be explained by quantum physics laws. Despite its esoteric and non-intuitive meaning, quantum tunnelling is a very well established natural phenomenon observed for example in energy production in the Sun and stars, alpha decay of heavy nuclei and is used in many modern day sophisticated devices such as the Esaki tunnel diode, a SQUID (Superconducting Quantum Interference Device) and the Scanning Tunnelling Microscope. Seven Nobel Prizes in Physics were awarded for discoveries and contributions related to quantum tunnelling effect.

nanoTrek(tm) devices consist of a large number of very narrow conducting wires (~100-200 nanometer width) deposited on an insulating substrate. Two such plates are brought to very close proximity and a bias potential is applied between the sets of conductors. The tunnelling current that flows between the plates is a function of the overlap "shade" area between the electrode conducting lines. If plates shift with respect to each other, a change in tunnelling current is observed and even the tiniest shift can be measured. Therefore if the electrostatic potential is applied to two misaligned nanostructures, the discrete irregularity in relative position can be detected with a sub-nanometer precision.

What are the benefits?

The patented technology underlying the nanoTrek^{TM} provides instrumentation that is smaller, cheaper and easier to use without compromising the stringent standards necessary for MEMS devices that demand extremely high levels of accuracy and precision. There are currently over 800 companies and labs that are involved in sensor or MEMS instrumentation, however, all use technology that is different from that developed by QPI (piezoelectricity, capacitance, Hall effect, interference, etc.).

More specifically nanoTrek^{TM} offers improved performance compared with existing devices in terms of accuracy, order of magnitude, operational range, robustness, and more efficient energy requirements and reduced mechanical inertia. The QPI instruments are being designed to be easier to handle, being more compact in size, self-contained and modular. Unlike other devices in this field, nanoTrek^{TM} differentiates itself from other high precision instrumentation by being cheaper as a result of lower fabrication costs that employ standard semiconductor fabrication processes, hence allowing the device to be mass-produced. The technology behind QPI's nanoTrek™, provides flexibility and creates efficiencies for industry allowing it to be multi-marketed and employed to multi-product applications.

Where is the product headed?

QPI devices will have unprecedented resolution and operational range in a multitude of applications. Since the domain of nanotechnology is encompassing a wide spectrum of industries, nanoTrek™ can be broadly employed as necessary instrumentation that supports these broad applications. For example the static and dynamic QPI devices can be used in:

- mask alignment in the microelectronic industry,
- nuclear testing monitors,
- accelerometers and gyroscopes (aviation and automotive industry, missile guidance)
- flow meters (medicine, precision injection moulding),
- micro-mirror alignment in optical switches (telecommunications)
- displacement and tremor sensors in mining, seismography, geology and tectonics,
- sonobuoys for submarine surveillance, environmental studies and marine biology
- acoustics, ultra-sensitive microphones
- metrology, scientific instrumentation
- measurements and standards laboratories,
- ultra-fine angle measurement instruments (e.g. diffractometers used for determination of crystallographic structures like protein, minerals and solids),

It is hoped that this innovative and evolutionary technology will aggressively enter into the high precision instrumentation market. It is forecast that QPI share will be an estimated US$23 million to 80 million by 2004. Currently QPI has a strong business plan and is looking to raise further capital to expand the business. The capital will be used to continue the research and development, build prototypes, extend and protect the IP portfolio, conduct market research, forge industrial alliances and commercialise the product.

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2.2 Product-Concept "Imaginings"

The following section provides some brief examples of the pioneering research being done in Australian public sector research institutions. The examples are but a sample of many nanotechnology-based research activities ongoing.

Typically the examples described are more embryonic product-concept "imaginings" and represent the culmination of several years of basic research efforts concentrated in Australian universities and public sector research institutions.

The necessary next stage for these "imaginings" is the commercialisation of these concepts and their industrial exploitation. To lesser or greater extent, these examples all need additional research, capital and industrial expertise to bring them to market.

Take special note that not all are product-concept; some examples deliberately illustrate service based capabilities in analysis; manipulation and fabrication at the nano-scale - a critical industrial capability.

It is stressed again that all the following examples are illustrative, and are not to be regarded as the best, or the only national capability in nanotechnology.

Table 4: Australian Product-Concept "Imaginings" - Potential Industrial Applications

Sector	Institution/University/ Company	Current Nanotechnology	Potential Applications
Advanced Manufacturing	**CSIRO Building Construction and Engineering**	Development of enhanced polymer based nanocomposites	***Stronger and smarter*** construction fillers
	CSIRO Manufacturing Science and Technology	Development of new nanoparticles polymers	***Smarter*** sunscreens, pharmaceuticals, paints, inks, textiles and cosmetics
	CSIRO Telecommunications and Industrial Physics	Sensor technology based on nanoparticle films	***Cheaper and smarter*** strain gauge applied in larger structures
	CRC for Microtechnology	Fabrication of carbon nanotubes and nanocapillaries	***Smarter*** microdevices such as micro- and chemical sensors, gauges and actuators.
		Preparation of nanosized metals, nanoalloys and semiconducting compounds	A broad range of ***smarter*** applications such as photocatalysis, conductive films and pastes, electromagnetic components, mulitlayered capacitors and storage media.
	Institute for Nanoscale Technology University of Technology, Sydney	Optical Technology	***Simpler, cheaper and smarter*** way of producing distributed lighting techniques
	Silicon Sands Pty Ltd Flinders University, University of South Australia	Organo silicon chemistry	***Cheaper and smarter*** method for developing silicon and silicon materials
Electronics, Computing and Communications	**Acton Semiconductors & Department of Electronic Material Engineering** ANU	Optical components	***Faster and smarter*** communication systems and dataways for information technology and telecommunications
	ARC Special Research Centre for Quantum Computer Technology University of Queensland, University of NSW, University of Melbourne	Silicon chip based on quantum physics	***Faster and smarter*** computer, which is up to one billion times more powerful than contemporary computers without increasing the size
Health Therapeutics and Diagnostics	**Department of Chemistry, Materials and Forensic Sciences** University of Technology, Sydney	Sol-gel process for treating hydroxyapatite of bone prosthesis and grafts	***Stronger*** load bearing bone replacements and prostheses
Platform Technologies and Services Multiple Industrial Applications/Uses	**NANO - Major National Research Facility** University of Western Australia, University of NSW, University of Queensland, University of Melbourne	New strategic alliance that will collaboratively provide facilities for the characterisation and manipulation of matter at an atomic level	This multi-university initiative is to create a ***smarter and more efficient*** way of centralising skills and instrumentation that is found across Australia to provide a unified and specialised service for groups researching in nanotechnology

CSIRO Building, Construction and Engineering

The concept and opportunity:

Structural and functional nanomaterials

Compared with traditional fillers, nanocomposites may offer significantly enhanced physical properties such as increased stiffness, strength, barrier properties, heat resistance and fire performance, without loss of impact strength and with improved aesthetics in a very broad range of common thermoplastics and thermosets. Because the nanoparticle sizes are on the order of the wavelengths of visible light, creation of nanocomposites does not change the optical properties such as transparency.

While the future potential of nanocomposites is tremendous, on the order of millions of tonnes by 2010, most current nanocomposite work is still more theoretical rather than commercial with limited types of nanomaterials being produced in small quantity instead of being made using the conventional polymer compounding equipment such as extrusion. Successful development and commercialisation of nanocomposites relies on (i) the ability to tailor the surface chemistry of the nanoparticles to enhance chemical compatibility between the modified nanoparticles and the polymer matrix for achieving nanodispersion; (ii) developing continuous processing technology to facilitate the actual nanocomposite formation during the manufacturing process.

Based on our strong capabilities in surface and interface/interphase molecular design of materials coupled with our extensive experience in innovative design and fabrication of polymer based composites including nanocomposites, a number of different nanomaterials are being researched and successfully developed by CSIRO for both structural and functional applications. Our nanomaterials development efforts were supported and enhanced by tapping into the broad range of expertise and equipment available and involving in multi-disciplinary collaborations.

Summary of the benefits/attributes of the technology

- Continuous process for nanocomposites fabrication
- Significantly improved physical and functional properties achieved with less than 5 per cent nanoparticle additions
- Cost effectiveness
- Weight reduction
- Properties not attainable by the conventional composite systems
- Environmental friendliness

What Investment is needed

CSIRO is seeking appropriate collaborators who can add value to these concepts.

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CSIRO Manufacturing Science & Technology

The concept and opportunity:

Nanoparticle production and applications

Our research focuses on the development of nanosized materials and new processes for application in polymers, pharmaceuticals, cosmetics/sunscreens, paints, coatings, inks and textiles. For example,

- **nanoparticle additives** with high-performance UV resistance are cost-effectively produced for use in sunscreens, cosmetics, plastics, paints and varnishes.
- **nanoparticle additives**, some acting as nucleating agents, improve the toughness, strength and clarity of polyolefins and others as ultrafine flame-retardants in polyolefins.
- **nanostructure** control in the manufacture of prototypes and failure analysis of products derived from inorganic powders and precursors.
- **membrane technology** through development of hybrid organic/inorganic nanostructures that act as filters for separating compounds at the molecular level.
- **nanotemplates** from synthetic opals, which produce "inverse opal" structures for microfluidic and catalytic applications.

Summary of the benefits/attributes of the technology?

- Ultrafine ZnO - low-cost, low-migration easily dispersed, improved UV absorbance, compatible with other polymer additives, transparent and often capable of acting at lower loadings than those required for similar additives. These ultrafine additives are commercially available, with a substantial fraction of the Australian nanophase sunscreen additive market and soon to appear in sunscreen products in the US and Europe.
- Improved clarity, strength, flexural modulus and haze, and improved dispersion of inorganic additives in polyolefins and extension of lifetime of outdoor materials subject to UV weathering. This technology is being commercialised.
- Protection of food and beverages against photodegradation.
- Resistance to corrosion, erosion and improvements in wear and barrier properties in polymer composites.
- Water purification and environmental clean-up, cleaner fuels and petrochemicals, purer medicines, desalination of water.
- Optical, catalytic and microfluidic applications.

Current collaborators

Micronisers Pty Ltd	Bottle Magic Pty Ltd
Uniqema Plc	Basell Pty Ltd
Culamix Pty Ltd	University of Texas, Austin
MTR, Menlo Park California	North Carolina State University

What Investment is needed

We are seeking collaborators with a global outlook, to develop downstream applications and markets for nanoparticles in the polymer, personal care, pharmaceutical and coatings industries.

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CSIRO Telecommunication & Industrial Physics

The concept and opportunity:

High sensitivity, low cost, printable sensors for integration into smart structures

The CSIRO is developing a range of novel sensors based on nanoparticle films that can be used to sense physical (e.g. strain) or chemical (e.g. gas) stimuli. The technology offers the opportunity to produce large (cm to m) strain sensors for monitoring structures such as bridges or buildings, as well as developing integrated arrays of micro-sensors that could be incorporated into structures such as aircraft wings.

How will it work? Why is it nanotechnology?

The sensor technology is based on modulating the electrical or optical properties of metal nanoparticle films in response to an external stimulus. On the one hand, by utilizing the electrical properties of nanoparticle films that occur at the nanoscale (e.g. quantum confinement and electron tunnelling effects) it is possible to produce extremely sensitive sensors for a range of physical or chemical stimuli. On the other hand, by utilizing the self-assembly properties of the CSIRO nanoparticle technology it is possible to produce these sensors simply and at low cost without the use of traditional thin-film deposition techniques such as vacuum evaporation or sputtering, which require expensive and complex equipment.

One example of such a sensor that has been developed is a new type of strain gauge based on nanoparticle films. Combining the high sensitivity of semiconductor strain gauges with the ease of application of metal foil strain gauges, nanoparticle film strain gauges on flexible substrates offer a higher-sensitivity, low-cost drop-in alternative to metal gauges while avoiding deployment difficulties associated with semiconductor gauges.

In comparison with normal strain gauges that require expensive, precision electronics to measure strains, the nanoparticle film gauges use very simple, low cost readout electronics. Moreover, nanoparticle film gauges can be ink-jet or screen-printed or sprayed directly onto the object to be tested, thus opening the possibility for novel, smart structures with integrated sensors. While this "smart paint" approach allows the conformal coating of irregular surfaces and small radii of curvature inaccessible with conventional gauges, it also lends itself to the fabrication of long-length gauges that enable efficient strain monitoring on large structures.

Summary of the benefits/attributes of the technology

- High sensitivity
- Low power dissipation
- Compact design
- Simple readout electronics
- Deposition by ink jet or screen printing, spraying or painting
- Compatible with photolithography
- Low cost
- Integration of metallic leads and contacts without extra deposition
- Long-lengths possible
- Direct application to test surface

The Nanoscience & Systems team consists of a multidisciplinary team, including expertise in theoretical and experimental physics, chemistry, (bio)sensor development, with core skills of self-assembly of nanoscale materials and nano-device fabrication. The team is actively engaged in a number of collaborative projects with internal and external stakeholders.

Where is investment needed?

CSIRO is currently negotiating with investors and alliances interested in the commercial applications of the strain gauges.

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CRC for Microtechnology/RMIT University

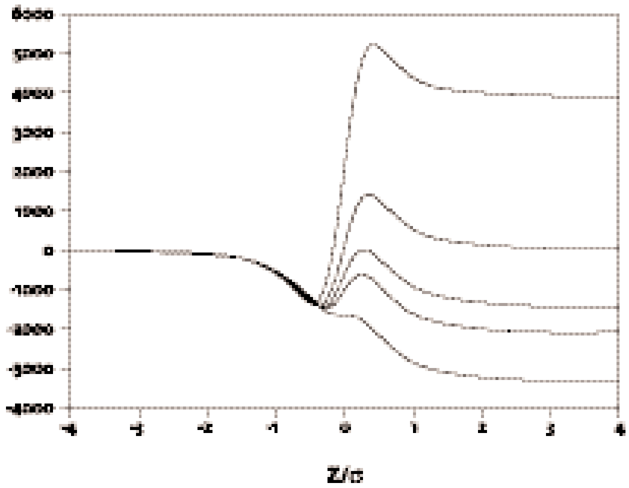
The concept and opportunity:

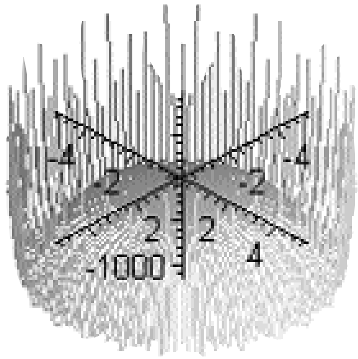
Nanoscience and Technology - Carbon nanotubes and nanocapillaries

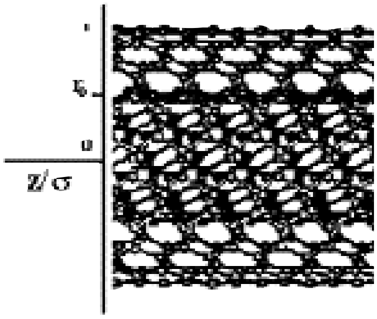
The ability to fabricate nanoscale pores, capillaries and channels with carbon has opened opportunities to exploit the unique mechanical, adsorption, electronic and optical characteristics of these systems that have confined spaces of a few molecular dimensions and wall thickness that vary from single, double and multi graphon sheets to continuum carbon microstructures consisting of five and six membered rings.

Carbon nanotubes have been examined for a considerable number of technological applications, such as field emission displays, hydrogen storage, chemical sensors, single electron transistors and nanostructure diodes. Microporous carbon tubes are finding application in molecular separation and as nano-reactors able to induce reactions through their enhanced internal potential fields that do not readily occur in the bulk phase.

For such applications, there is a strong requirement for precise definition of the molecular behaviour of species both within these confined spaces and on their surfaces, and thus link material properties, performance characteristics to the new synthesis capabilities that are able to generate these novel nanostructured materials.







Left: Upper - Potential energy imposed on a molecule as it approaches a carbon nanocapillary along the centerline (r_o from 0.25 to 0.29 nm)

Lower - Double wall carbon nanotube illustrating coordinate axes

Right: Radial field distribution imposed on a molecule within a single wall carbon nanotube, illustrating the impact of the discrete sp^2 carbons of the single graphon sheet

Our research focuses on the relationship between the architecture of these nanostructures and the potential fields within and outside nanotubes and nanocapillaries which dictates the energy barriers to entry, transport diffusion, adsorption potential and spatial distribution, and which influences their performance in microdevices such as micro-sensors, gauges and actuators.

Summary of the benefits/attributes of the technology

- Control of molecular interactions with nanoscale carbon structures
- Design and evaluation of nanocomposite films for sensors and other microdevices
- Descriptions of the attractive and repulsive fields that influence barriers to entry and exit at the nanoscale

Where is investment needed?

The CRC is seeking investors and alliances interested in the commercial applications of the technologies above.

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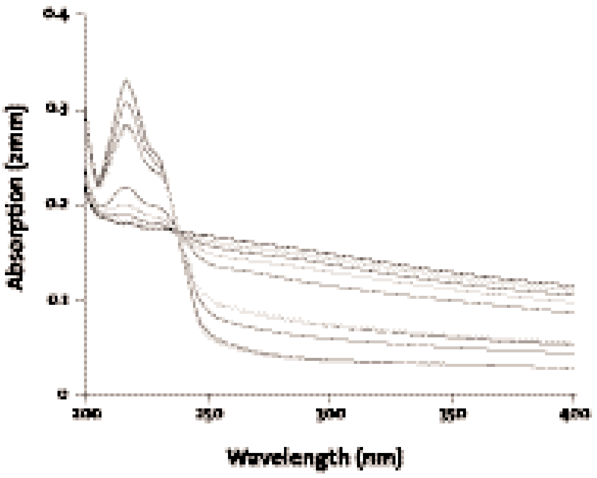
CRC Microtechnology/RMIT University

The concept and opportunity:

Nanoscience and Technology - Nanoparticles and Quantum Confinement

Particles of nanodimensions are now critical to advancements in numerous applications that include physical, chemical and bio-sensors, photocatalysis, conductive films and pastes, electromagnetic components, magnetic fluids and storage media, multilayer capacitors, and phosphors. Many of these applications are due to the unique dependence of the electronic and optical properties on the particle size of either the metal or semiconductor nanoparticles. This quantum size effect of nanoparticles with diameters less than 10 nm is beginning to be used in biological systems for molecular recognition and photoelectric information devices associated with its nonlinear optical properties.

Our research focuses on the preparation of nanosized metals, nanoalloys and other semiconducting compounds, with special reference to magnetic alloy nanoparticles and chromatic semiconducting particles as platforms for biosensors. One such system is platinum nanoparticles which are known for their catalytic and photocatalytic activity and which are now finding applications in micro and nano-electronics as physical and chemical sensors.



Controlled ligand exchange of Pt species and reduction to form Pt nanoparticles in a stable dispersion

The properties of nanoparticles critically depend on their morphology, size distribution and aggregation characteristics. We focus on the improved microdevice performance through systematic and controlled synthesis of nanoparticles from soluble metal precursor complexes. Well-separated nanoparticles with narrow size distribution are fabricated which are able to demonstrate their unique optical adsorption spectra characteristic of the excitation of the plasmon resonances and/or interband electronic transitions. Our synthesis is based on controlled ligand exchange in solution to achieve the appropriate reactive intermediates prior to systematic reduction to the metal nanoparticle.

Summary of the benefits/attributes of the technology

- Controlled synthesis of well defined nanoparticles
- A consistent starting material for further fabrication of nanoparticle based thin film microdevices
- Improved microdevice performance through tailored electronic and optical properties

Where is investment needed?

The CRC is seeking investors and alliances interested in the commercial applications of the technologies above.

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The concept and opportunity

Super Side-Light Technology

Super side-light is a method of producing low-cost distributed lighting using nanotechnology. The one-step manufacturing process produces a large diameter single core flexible polymer optical fibre, which, combined with high-efficiency new-generation Light Emitting Diodes ("LEDs") as end illumination, produces a new kind of lighting which is cool, glare free, low voltage and free of electrical noise. **Super side-light** is applicable to a vast array of lighting system and applications, many quite novel, others superior to existing options. Examples of the various applications include: safety, display and advertising signage, neon sign replacement, refrigeration lighting, display cabinet lighting, lit clothing and jewellery, solar powered lighting and general illumination.

How will it work? Why is it nanotechnology?

For the first time a simple manufacturing process has been established and implemented (underlying product already available) which allows light to be transmitted along a flexible single core fibre cable where light is emitted along the cable in a controlled way through the sides. This provides a uniform brightness along the cable similar to a neon tube. This is achieved by special polymer nanoscale and microscale additives in the cable, which allow a balance between transmission and scattering of the light along the cable without significant light loss from absorption or shift in colour.

Summary of the benefits/attributes of the technology?

Super side-light technology is simple, low-cost and easy to make, durable, unique, available in diameters from 2 mm to 20 mm and works from 10 cm to 30 metre lengths. The end product is easy to use and install, totally flexible and generates a low glare, making it extremely safe and user friendly.

Current collaborators

University of Technology, Sydney ("UTS") currently collaborates with fibre cable manufacturer PolyOptics Australia Ltd, where the parties hold a joint patent in relation to the technology underlying Super side-light fibre and the novel processes involved in its manufacture.

What investment is needed?

Investment is needed for the numerous applications based on the development and exploration of further fibre enhancements and variants. These industry opportunities are available to lighting and lighting system manufacturers, signage and safety system manufacturers for partnerships to develop new products.

The concept and opportunity

Light Diffusion Technology

Light diffusing material for skylights and roof glazing incorporating custom-designed nanoparticles can control the solar heat gain without reduction of light transmittance at very low additional cost, certainly much lower than conventional alternatives such as multilayer thin films.

How will it work? Why is it nanotechnology?

This technology utilises unique and highly efficient spectral control properties of certain special simple nanoparticles, and microparticles with nano-thin coatings acting as additives to the diffuser material. This approach has already been proven in UTS-developed clear glazing products that will be commercially available in mid-2002.

Summary of the benefits/attributes of the technology?

There is a major problem with existing skylights, translucent walls and light diffusers in warm-to-hot climates with heat gain from the sun, as heat fluxes onto a roof are very much higher than onto a vertical window. This can annul the advantages of the good illumination they can supply. These new doped polymers are easily manufactured using existing extrusion lines for translucent polymers. The total system remains low cost as very few particles are needed. Comfort gains are substantial so value added to buildings probably outweighs many times over the small additional costs involved in manufacture. The potential market for diffusing polymers used in buildings in warmer climate areas like southern and western USA and Australia is large, and we believe that a low-add-on cost heat reduction product could achieve significant penetration of these markets

Current collaborators

UTS is currently engaged in collaboration with particle suppliers such as Sumitomo Metal and Mining. Furthermore, they have identified several manufacturers, in Sydney and elsewhere, who could potentially fabricate these materials immediately.

What investment is needed?

UTS are actively seeking interest in manufacturing, joint venturing or investment.

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Polymer Science Group of Flinders University and Silicon Sands Pty Ltd

The "Imagining" team.

Silicon Sands is a spin off company associated with the Nanotechnology Centre at Flinders University. The technology underlying the company was developed by Professor Janis Matisons of the Polymer Science Group now at Flinders University, which remains a major shareholder of Silicon Sands.

Why are they interested in Nanotechnology?

Silicon Sands is developing a revolutionary new method of producing silicon that is more energy efficient and cost effective compared with the existing procedures that are currently available. This technology can potentially have widespread applications, as silicon is also one of the most versatile materials in use. There are over 45,000 different compounds derived from silicon. These are extensively used in a variety of domestic and industrial markets, including the pharmaceuticals, telecommunications, construction and automotive sector, and have broad chemical, electrical and mechanical applications. Despite this widespread application, the method for developing silicon has not changed or been significantly improved over the last 50 years. The current technique of processing silicon consumes expensive raw material and an extremely high level of energy, and it is these factors that greatly contribute to the cost of high silicon in the existing market. In this light, it is hoped that this pioneer silicon processing method will have profound effects by considerably changing the silicon and silicon materials market.

How does is work? Why is it Nanotechnology?

This work is based on the research undertaken by Professor Matisons, who has conducted extensive research in the area of organosilicon chemistry, particularly in silicon-mediated reactions, silicon based ceramics precursors, liquid crystalline siloxanes and new siloxane copolymers. Fundamental research has been focused on researching new routes for the preparation of silicon based metals where various Australian minerals, beach sand, selected silica grades and cement are subjected to high temperature sintering processes and thermal activation of various mixed silicates to yield highly reactive intermediate silicon complexes.

Using specific chemical control of colloidal nanostructures, high yield synthesis of key silicon intermediates is possible, thereby avoiding the energy intensive routes of the existing "direct process." Such intermediates are then used to generate various silicon based materials (such as silicone polymers and oils), using the silicon-mediated reactions referred to above. Instrinsic to the technology are separation procedures that enable the 'pure colloidal silicon stream', to be isolated from, say, a 'pure alumina stream,' using aluminosilicates such as common glass as the starting materials.

"Just as antibiotics, the silicon transistor and plastics affected nearly every aspect of society in the 20th century, nanotechnology is likely to have profound influences in the 21st century," Prof. George Adams (Purdue University) said. Furthermore, he states, "the development of molecular electronics and devices that self assemble, similar to the growth of complex organic structures in living organisms will soon be possible using nanotechnology. Theoretically, once set in motion, such self-assembling devices would build themselves, making electronics processing far less expensive than conventional semiconductor processing."

What are the benefits?

It is anticipated that the proposed technology will produce a cheaper and easier method of producing silicon. The implications of the Silicon Sand process will drastically reduce the cost of the final product by not only significantly reducing the energy consumed in the manufacturing process, but also by exploiting alternative raw materials, which are cheaper and less detrimental to the environment.

The current process employed to produce silicon products involves a raw material called alpha quartz. Quartz is a mined mineral that undergoes extensive processing to be converted into silicon. Under conventional existing methods the quartz is placed into an electric furnace and heated to extremely high temperatures of 1300 to 1900°C for prolonged periods of up to 16 hours. During this procedure, two expensive metals are also added as essential catalysts to drive the process. The produced intermediate silicon metal requires additional processing, whereby it is further heated to 400 to 500°C in the presence of chloro-hydrocarbons and more metal catalysts, to produce the silicon based materials that the industry converts to the large variety of products available today.

As a result of the exceptionally high heating requirements of this processing protocol, this current method involves significantly high capital plant costs in relation to setting up special ceramic furnaces that can withstand the ultrahigh temperatures. Furthermore, the high energy consumed by the process also greatly contributes to the production costs. It is estimated that the power that is required to melt the quartz represents approximately 20-30 per cent of the production costs. Other factors that contribute to the expensive production costs are associated with the high plant maintenance and upkeep costs necessitated as a result of hydrochloric acid by-products.

It is planned that Silicon Sands new processing method will alleviate these current problems associated with silicon production. The new technology will use any sand as the raw material, and employ a lower heating process of 200°C for 5 to 8 hours, without the addition any metal catalysts. This method will reduce the plant costs by approximately one tenth and significantly reduce energy consumption. Furthermore, the cost of production is also reduced as a result of the material components used in the process. The new process exploits the use of sands as the basic raw material for silicon production. Sand is seen as a cheaper alternative to quartz as higher purities of sand are far more readily available and more easily to acquire compared with high purity quartz.

Where is the technology headed?

Silicon is an important element for a wide spectrum of industry sectors. Worldwide 880,000 tonnes of silicon material is used every year; this figure has steadily increased at 4-5 per cent per year over the last 20 years. It is estimated that the worldwide silicon sales from the top ten major silicon companies are approximately USD18 billion per annum. Therefore, Silicon Sands may potentially secure a large portion of this market share, if they can successfully develop their technology to penetrate the silicon market.

What investment is needed?

Currently, the research carried out at by the Polymer group has made it possible to produce low cost silicon chemical from a possible nine alternative methods. This technology is now in the critical stages of development as further investigation and evaluation is required for scale up to commercialisation. Silicon Sands is seeking additional corporate funding that will enable the further development and optimisation of the chemical process that provides the unique processing method for both silicon and silicon chemicals. Silicon hopes to patent this technology to protect and preserve the monopoly position they currently hold in relation to this technology.

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Acton Semiconductors Pty Ltd and Department of Electronic Materials Engineering, Australian National University

The "Imagining Team"

The Electronic Materials Engineering Department ("EME") is located within the Research School of Physical Sciences and Engineering at the Australian National University ("ANU"). EME was established in 1988 to act as a focus for interdisciplinary materials science research that underpins fabrication of advanced (semiconductor) components that are the smart enablers of information technology and telecommunications ("ITT") systems. The main research thrusts have increasingly involved materials growth, innovative materials processing and novel device development at the nanoscale. To support this research, the department has established an integrated suite of facilities that is unique in Australia and valued at over $15 million. There are currently over 30 EME personnel contributing to the overall research effort including internationally renowned research staff, PhD students and dedicated technical staff that are assisted by a similar number of national and international research collaborators. About half of these creative individuals have had direct contributions to the novel technology described in this case study.

The Concept and Opportunity

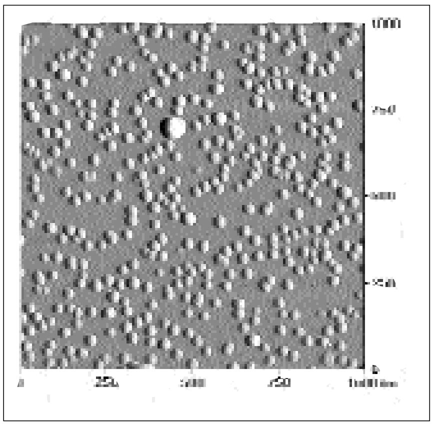
From its inception, EME focussed its research efforts on semiconductor technology in areas that underpin the ITT industry sectors. The philosophy was to establish cutting-edge research programs and put in place the expertise, resources and international collaborations necessary to make a major impact in the field. A large fraction of this research effort has specifically focussed on developing, designing and building the tiny semiconductor structures and components that are essential for optical communications systems. Indeed, such ultra-small semiconductor devices are the building blocks that are currently driving the IT and communications revolutions. For example, communication systems and fast dataways are based on light as the carrier of this information though optical fibre. The smart components of fibre networks are the semiconductor devices that not only provide the light signals but also detect, modulate and amplify them. They derive their unique properties as much from their nanoscale dimensions as from the materials in which they are made. This is particularly true of light emitting and receiving devices in which the fabrication of their crucial active parts involves nanotechnology to craft layer upon layer of different compound semiconductors, the thickness of each layer being as small as a few atoms wide.

To manufacture these small devices requires sophisticated equipment and facilities and very many processing steps, from growth of the active layers to depositing metal and insulating layers and then patterning on a nanoscale. Developing entirely new devices based on novel nanostructures is even more demanding. It necessitates an activity on the scale of the EME effort at ANU: an innovative research team and an integrated, world-class suite of facilities. For example, innovation and research breakthroughs in this area of technology require flexible facilities for growing the atomic semiconductor layers, diverse diagnostic facilities for measuring the structural, electrical and optical properties of such layers, as well as novel and adaptable facilities for processing the layered structures such as EME's ion beam modification and selective oxidation capabilities. Indeed, it is EME's cutting-edge R&D capability in this field that has led to several technological breakthroughs, such as the highest power (edge-emitting) semiconductor lasers yet made, laser arrays in which the wavelength (or colour) of emitted light from individual lasers can be tuned, novel photodetectors operating at infra-red wavelengths, ultra-fast photodetectors for high speed communications, surface emitting lasers in which the emitted light can be steered and so-called quantum wire and quantum dot lasers in which the active region is confined to nanosize in two or all three dimensions. These innovative semiconductor devices are examples of the types of components that will be needed in advanced communication systems envisaged for future fast dataways and fibre-to-the-home.

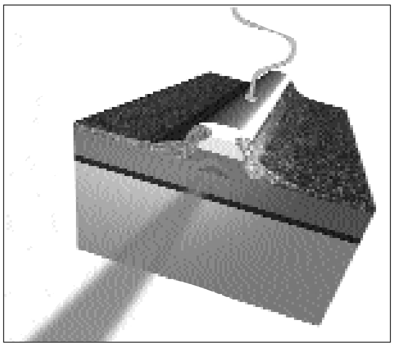
How does it work? Why is it Nanotechnology?

Quantum dot lasers are an example of innovative devices that developed out of the EME research effort. Figure A shows an array of ultra-small indium arsenide quantum dots, which are nanostructures in their own right that have been grown on a gallium arsenide substrate. In order to make a laser, particular atomic layers of different materials

A



B



An array of indium arsenide nanocrystal (A) used to convert electrical energy into discrete wavelengths of light (B). This discrete light can be employed in lasers that have various optical communication applications.

need to be grown above and below the quantum dot layer in a sandwich-type structure illustrated in Figure B. When (metal) contacts are made to connect the quantum dot laser to the outside world, an electrical voltage can be applied and electrical energy converted to light in the active quantum dot region, as shown. The key advantages of quantum dots over larger laser structures are the extremely sharp wavelength (colour) of light emitted and the low threshold current, making such devices ideal as narrow, highly efficient and cost-effective light sources for optical communication systems.

What are the benefits?

The innovative EME semiconductor technology that covers a range of devices of importance to future communications systems, is the culmination of 12 years of effort. The potential benefits of the EME semiconductor technology in future optical communications systems are considerable. The design and performance of the high power lasers are attractive in emerging metropolitan optical networks, tunable devices are essential for future bandwidth requirements, steerable devices are very attractive as a means of assisting device integration and quantum dot lasers are already being touted as the preferred devices of the future as a result of dramatically-enhanced performance.

Where is the technology headed?

Acton Semiconductors Pty Ltd ("Acton") is a spin off company that has been established to exploit the novel technology and IP developed at EME in the area of optical components. The work undertaken at EME has led to several patents and provisional patents on different aspects of the technology, with the ANU providing seed funding for these developments. The present emphasis, while the high tech communications sector is depressed with few current investment opportunities, is to continue to develop novel IP of substantial significance for future communications networks. The strategy is that rapid development of new technology and devices at this stage will maximise the investment/exploitation opportunities for ANU/Acton when the industrial climate turns around. Few new high tech companies have access to the depth of R&D expertise and infrastructure that is available in EME at the ANU. Together with innovative, patented technology, this ability for rapid development gives a substantial competitive advantage to the final products, whether they are ultimately manufactured by Acton or the technology licensed to another company.

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ARC Special Research Centre for Quantum Computer Technology

The "Imagining Team"

The Australian Research Council ("ARC") Special Research Centre for Quantum Computer Technology ("the Centre"") has been recognised internationally as one of the leading quantum computer centres in the world. Quantum computer technology has the potential to deliver vastly increased levels of processing power by employing the principles of quantum physics in how the computer operates.

The Centre was established in January 2000 and receives funds from the Commonwealth through the ARC and other participating institutions. It is a multi-university collaboration and consists of three research nodes at the University of New South Wales, University of Queensland and University of Melbourne. It also maintains an important collaboration with Los Almos National Laboratory in the US.

The Concept and Opportunity

It is believed that the current computer industry, which is largely based on semiconductor technology, is approaching its full capacity and will no longer be able to extend beyond a restricted upper limit of speed and processing power. The fundamental construction underlying current technologies is founded and also bounded by the laws of classical physics. However, by applying quantum mechanics to computer design, and developing a completely new and innovative silicon chip at the atomic level, it is hoped that this new nanotechnology will provide the ability to build a 'supercomputer' that is significantly more powerful than traditional computers used today.

How does it work? Why is it Nanotechnology?

The Centre's extensive research is divided into multi-coordinated programs that employ a widespread array of nanofabrication and quantum measurement facilities and equipment provided at each of the university nodes. The focal objective of the research is to explore fundamental physics at the atomic level, and to exploit this technology to develop a solid-state quantum computer in silicon together with other high potential implementations. Three Centre facilities are highlighted below: Semiconductor Nanofabrication Facility (SNF), Atomic Fabrication Facility (AFF) and National Magnet Laboratory (NML). The SNF and AFF comprise Australia's foremost nanotechnology capabilities and NML houses highly advanced quantum measurement equipment. Taken together with other facilities in the Centre this comprises an Australian capability to fabricate and measure the key functional element of a silicon quantum computer.

What are the benefits?

Primarily, the work undertaken at the Centre will ultimately provide quantum based computers that are faster and more efficient; the processing power will far exceed that of the conventional computers employed today. These supercomputers have the potential to revolutionize the computer industry, alleviating the current limitation that restricts traditional computers and open the way for new computer applications. It is predicted that they will be capable of solving problems that are impossible on even the most powerful contemporary computer, providing a more superior level of intelligence.

Another advantage of the Centre's solid state quantum computer is that it is based on silicon, enabling a smooth transition from existing to new silicon chip industry.

Where is the technology headed?

Although a practical computer has not been completed there is already strong international interest in this unfolding Australian research. The group has strong international strategic alliances, principally with the US, and potential partners who have expressed interest in the Centre's work are major players in the US semiconductor industry.

Semiconductor Nanofabrication Facility (SNF)

The Semiconductor Nanofabrication Facility (SNF) at UNSW is a complex of laboratories engaged in R&D scale production of semiconductor devices, such as silicon integrated circuits. The key feature which sets SNF apart from other semiconductor plants is its capability to create nanoscale devices with feature sizes of order 10nm. This is ten times smaller than the smallest feature on an Intel processor chip and is by far the smallest feature size capability in Australia. The technology is based upon sophisticated electron beam lithography systems which have been optimised for ultra-small feature sizes, together with a suite of advanced semiconductor processing tools for gas-plasma deposition and etching, ultraviolet photolithography, silicon MOS wafer processing and high-purity metal deposition. Sample analysis is achieved by on-site imaging systems including high-resolution electron microscopy and atomic force microscopy with resolution down to 1nm. This advanced equipment is housed within a purpose-designed 300m^2 three-level suite of class-3.5 and class-350 clean-rooms with tight temperature, humidity and environmental controls. The facility was established in 1995 and is operated within the School of Physics and the School of Electrical Engineering & Telecommunications at UNSW. The primary research focus at SNF is the fabrication of prototype devices for a functioning silicon quantum computer, although a range of other projects are also supported, including: quantum wire devices, photovoltaic devices, micro-electro-mechanical systems (MEMS) and optical waveguides for communications systems.

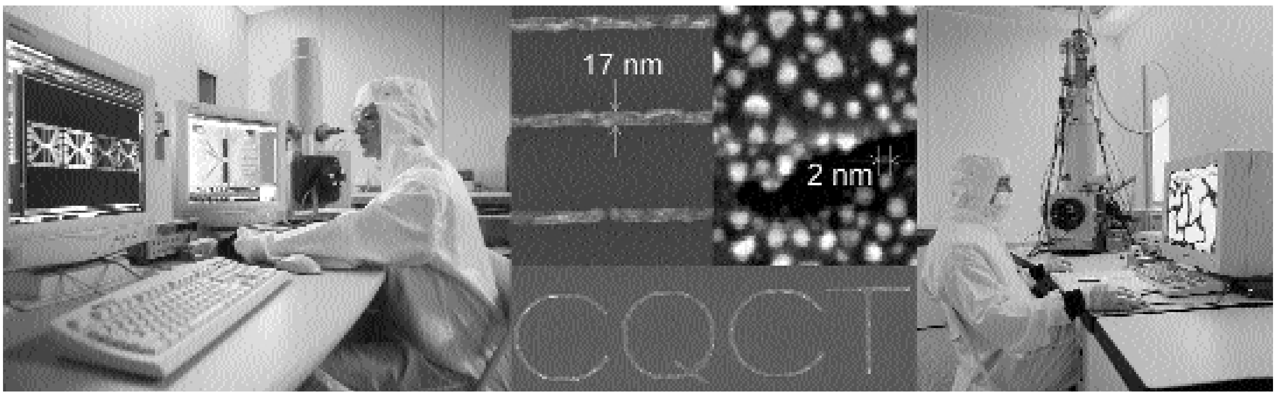
Atomic Fabrication Facility (AFF)

The Atomic Fabrication Facility (AFF) was established in 2001 to realise the fabrication of atomic-scale devices in silicon and in particular a silicon-based quantum computer. The facility houses two separate ultra-high vacuum (UHV) systems with atomic lithography and crystal growth capabilities. The first system is an Omicron variable temperature scanning tunneling microscope (STM) with a molecular beam epitaxy (MBE) deposition chamber.

One chamber of this system houses a combined STM and atomic force microscope (AFM) that is used to image silicon surfaces and perform atom-scale lithography. The second UHV chamber houses a silicon evaporation source for the growth of epitaxial silicon using the MBE process. This system was installed in 1998 and to date the majority of the pioneering work on the fabrication of atomic dopant arrays in silicon has been performed here.

Figure 1 demonstrates the fabrication strategy for atomic precision placement of individual phosphorus atoms as qubits on the silicon surface. The STM images on the right show how the STM has been used to selectively open an array of atom-sized holes in a barrier layer of monohydride on a silicon surface. Exposing the entire surface to phosphine (PH_3) gas lead to the adsorption of PH_3 molecules directly to the silicon surface only where the atom sized holes were made. By programming the STM tip to desorb a series of single atom sites in the monolayer it was thus possible to produce a linear array of phosphorus atoms on the surface. This programmed production of P atom arrays, which was patented by the Centre in 2000, is central to our bottom-up atomic fabrication strategy of the silicon quantum computer.

Electron beam lithography system based on FEI XL30S FEG-SEM (left), which has demonstrated sub-20nm metal features and an imaging resolution below 2nm. This complements the 100keV EBL100 system (right) at the Semiconductor Nanofabrication Facility.



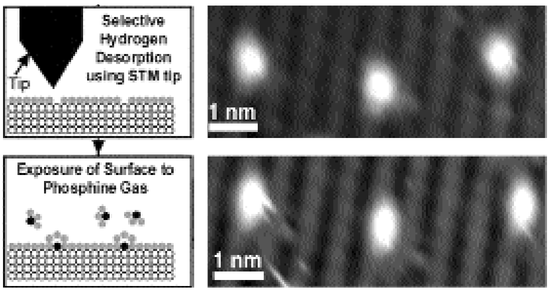


Figure 1: A schematic of the fabrication process for an atomic array of phosphorus atoms as qubits in silicon with corresponding STM images of the surfaces.

The array can then be encapsulated in overlayers of high-crystalline-quality Si in the molecular beam epitaxy growth chamber to form atomically precise arrays of phosphorus in silicon.

In mid-June 2002 a second multi-chamber STM-SEM/MBE system capable of 4" wafer device quality silicon will be installed. This system has the capability to incorporate a scanning electron microscope (SEM) on the STM system that will allow registration markers to be easily found and a specially designed optical position readout system to allow precise alignment of features during successive fabrication steps. This machine will allow the fabrication of 3D electronic devices in silicon at the atomic scale.

National Magnet Laboratory (NML)

Measurements and characterisation of quantum devices are performed in the National Magnet Laboratory. The 200m^2 laboratory houses sophisticated measurement facilities for the characterisation of semiconductor and nano-structure devices. Measurements of sub-nano-volt signals from DC to GHz frequency can be made at temperatures ranging from 10 milliKelvin to room temperature, at constant magnetic fields up to 16 Tesla or pulsed magnetic fields up to 60 Tesla. The laboratory has 3 low temperature dilution refrigerators, configured to allow a variety of experiments to be performed.

The first dilution refrigerator is an Oxford Instruments K100 system, allowing characterisation of a variety of devices at temperatures down to 20mK and magnetic fields to 10 Tesla. A second refrigerator has been custom designed to allow ultra low temperature measurements of single electron devices at frequencies up to the Gigahertz range. This is achieved with a mixture of semi-rigid and flexible coaxial cables as well as ultra-low noise cryogenic amplifiers installed into the insert. These two refrigerators are housed in copper screened rooms, which shield the ultra low temperature measurement platforms from external noise sources. The third system is a unique "plastic" refrigerator, which has a superconducting 9T magnet and can also be used in pulsed magnetic fields. Optical measurement systems include a tuneable Ti-Sapphire ring laser pumped by an Argon laser, and a triple-pass high-resolution spectrometer fitted with CCD detectors. Experiments requiring large magnetic fields are conducted in a specially constructed blast proof room, capable of pulsed magnetic fields up to 60 Tesla.

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The concept and opportunity

Coral has been used for a number of years as a starting point in the manufacture of bone prostheses and grafts by converting it to Hydroxyapatite - a lightweight porous material with many of the properties of natural bone. Unfortunately, the material in this state is not strong enough for most prosthetic requirements and it requires further treatment, such as surface coating developed by UTS, to gain the required strength and durability in the body.

How will it work? Why is it nanotechnology?

UTS has developed a sol-gel process for treating the Hydroxyapatite with a nanocoating that provides the necessary strength and durability without clogging or closing the pores in the material which are necessary for initiating bone regrowth and tissue attachment. The proprietary coating is extremely uniform and coats the material to a thickness of a few tens of nanometers. It is stable in contact with body fluids and is not rejected. The coated product is 100 per cent stronger than the uncoated Coralline Hydroxyapatite. This results in a load-bearing bone replacement material which is not currently available.

Summary of the benefits/attributes of the technology?

The UTS technique represents a significant improvement with respect to materials currently available for bonegraft applications in orthopaedic and maxillofacial surgery.

Current collaborators

Previously Bright Eyes Pty Ltd was involved in related applications and discussions with venture capital companies are currently underway.

What investment is needed?

Investment is needed to develop this process to pilot scale production and to begin animal trials.

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Nanostructure Analysis Network Organisation - NANO

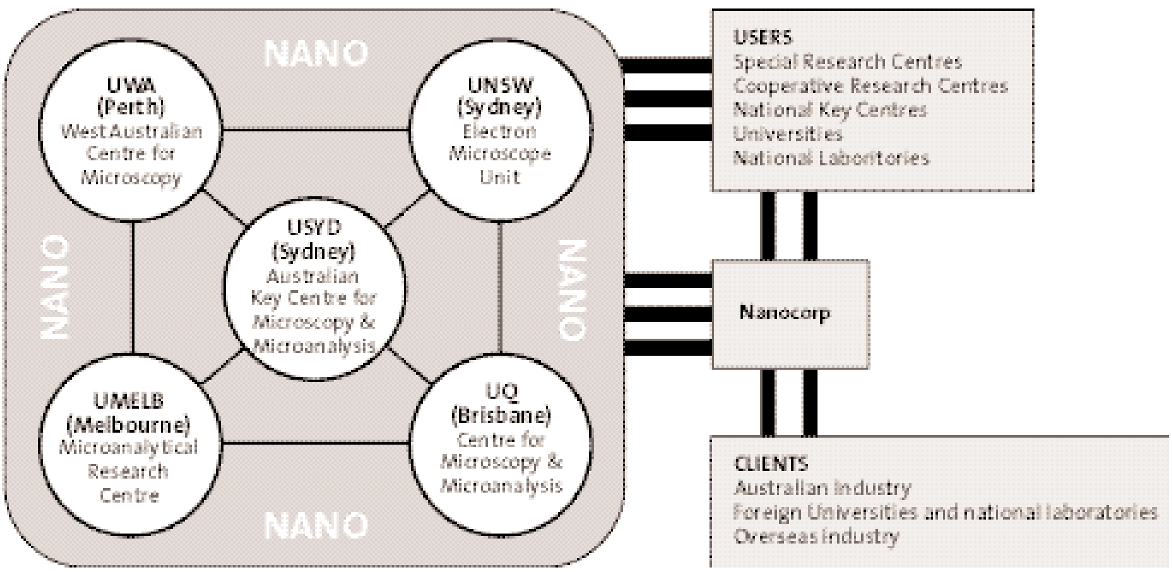
The "Imagining Team"

The Nanostructural Analysis Network Organisation is a Major National Research Facility ("NANO-MNRF") established under the Commonwealth Department of Education, Science and Training. NANO is an unincorporated joint venture between University, State and Commonwealth Governments and industry partners. The NANO-MNRF will provide the peak Australian facility for the characterisation and manipulation of the atomic and molecular structure of materials. Combining these centres will provide a central platform for nanotechnology-related research and therefore will enable Australia to become an active participant of this rapidly expanding field.

structure-function relationships that enable innovation in nanotechnology and biotechnology. The NANO-MNRF will develop and support a commercial arm to provide a vehicle for the rapid commercialisation of research.

How does is work? Why is it Nanotechnology?

Australian scientists and engineers need access to a national facility for nanostructural analysis to understand and control the relationship between processing and properties of both physical and biological devices and systems. There are at



The Concept and Opportunity

The NANO-MNRF will provide the peak Australian facility for nanometric analysis of the structure and chemistry of materials in both physical and biological systems. NANO will operate and maintain state-of-the-art facilities for the characterisation and manipulation of matter at the atomic and molecular scale. With a primary focus on microscopy and microanalysis, this network organisation will create collaborations so as to explore and define the

least two important research trends that drive the need for a national facility:

- The increasingly sophisticated requirements of innovation in materials requires specialised instrumentation that will provide analysis of materials at the atomic and molecular level. The trend towards increasing miniaturisation of the critical dimension of materials and devices is well-known and recognised. 'Top-down' research (miniaturisation) is now overlapping with 'bottom-up' research (atom and molecular self-assembly and manipulation) to place acute and rather new types of requirements on microscopy, microanalysis, characterisation and metrology. The nodes of the national network are highly complementary because they collectively allow complete structural and chemical analysis of materials at an atomic or molecular level. Analysis at this level of detail is vital in fields such as nanotechnology and biotechnology, where sub-units with atomic or molecular dimensions control function. No instruments of the type requested in this proposal currently exist in Australia.

- The increasing level of demand for research involving characterisation of structure and chemistry at high resolution is also coupled increasingly with research involving the fabrication of new structures based on the manipulation of individual atoms and molecules. Microscopy is passing from the passive approach involving observation and inference to an active process invoilving design and construction of nanomaterials prototypes.

What are the benefits?

- To establish new national and international linkages through a network organisation for resource-sharing between a grid of new and existing instrumentation in microscopy and microanalysis.
- To become the peak Australian facility for nanostructural analysis through the delivery of new capabilities in atomic and molecular level imaging, analysis and manipulation so as to support and enable Australian nanotechnology and biotechnology research. In pursuing this objective, NANO will develop and promote strategically Australian expertise and intellectual capabilities as well as instrumentation resources for nanostructural analysis.
- To form an incorporated joint venture company between the institutional and corporate partners. This proprietary limited company, referred to as NANOCorp for the purpose of this Plan, will act as the commercial-arm of NANO, will have a global focus and will develop a portfolio of major contract R & D projects and intellectual property in nanostructural analysis and advanced materials design and prototyping.

Where is the technology headed?

- Drug delivery platforms (smart drug delivery systems)
- Light alloy design (for faster lighter cars, air and spacecraft)
- Photonic nanomaterials (for the next generation of telecommunications technology)
- Structural biology (drug design, smart drugs)

What Investment is needed

A cash investment into the research portfolio is possible and this is expected to be project-specific. Alternatively, an external party may purchase equity in NanoCorp. It is also possible to purchase additional node status in NANO. Finally, the NANO-MNRF undertakes contract research and fee-for-service work by appointment with the Executive Director.

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Summary Overview

3 Final Summary Overview - Australian National Capabilities

The collection of case studies above shows clearly that Australia has very strong capabilities in nanotechnology.

However, nanotechnology exploitation in products and services that are "smaller, cleaner, cheaper, faster and smarter" are mostly still in an embryonic stage and require further investments from both the private and public sections to take full advantages of the technology.

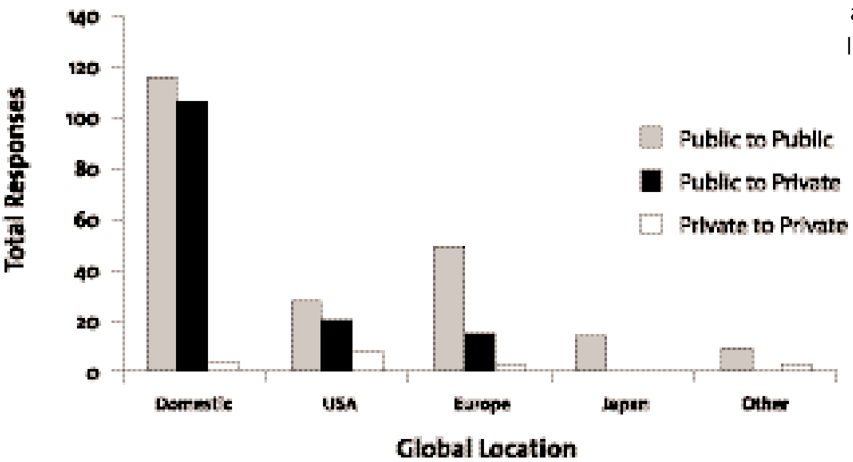
The current state of Australian nanotechnology-based industrial development is not as extensive compared with other OECD countries and many organisations and companies that could benefit are yet to be sufficiently aware of the opportunities to take the next steps of active investment and industrial application.

An important message to industry as shown by these case studies is that nanotechnology is not the sole domain of academia and high-technology start up companies. Established companies such a Orica Ltd have such interests and that it is the cost-benefit attributes of the technology that are important - not a semantic debate as to what nanotechology is, or is not.

Current nanotechnology-related technology partnering is mostly between public sector institutions rather than between the public and private sectors. The relationships disclosed in a prior report[1] (examples restrained due to commercial confidentiality) show both R&D-based and business-based alliances and joint ventures between and like entities in the US, EU, Japan, Korea lia is very quickly developing global links

Australia already hosts strong talents and resources in the nanotechnology area. These need to be accelerated and enriched by the following activities, some of which are gaining recognition and pace.

Figure 4: Key Alliances and Collaborations



[1] Data - Scoping Study in Nanotechnology Technology Diffusion – Ernst & Young, Freehills Technology Services & Howard Partners 2000

Some Ideas to Support Nanotechnology Uptake in the Short and Mid Term

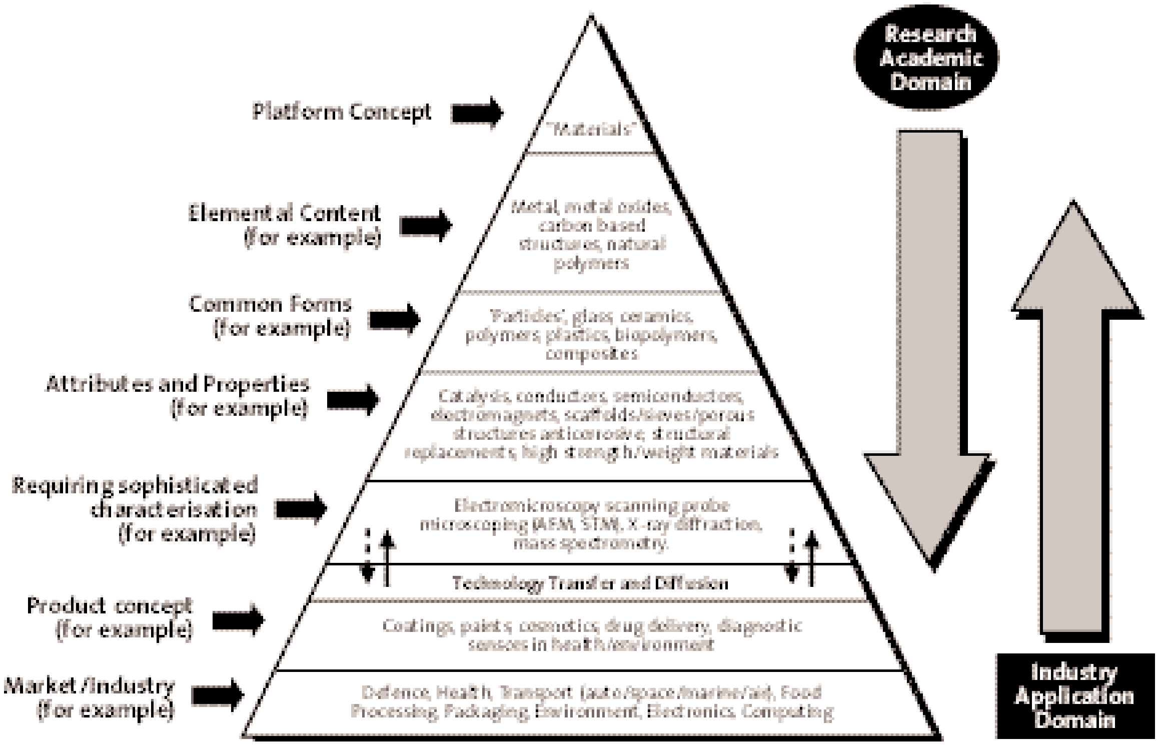
The foremost need is to build industry awareness, for example:

- By building national networks to raise awareness and knowledge of potential nanotechnology applications in all sectors and markets covered by manufacturing industry, eg, national nano-materials forums and on-site demonstrations.
- Provide for a national networked capability for ultra-structural characterisation and analysis of all material types and material composites.
- Provide like networks to systematically direct research, training and teaching initiatives in nanotechnology eg within universities/CSIRO.

Next in importance is to better leverage current capability and strengths, for example:

- Show willingness to trade complementary assets. Australia has a less developed micro-electronics, semi-conductor industry, or chemical industry, compared with say Japan or Korea. Australian may need to seek alliances eg. trading biotechnology for electronics.
- Encourage "adaption and application" rather than over invest in "invent and discover" ie better use knowledge generated by other nations as much as generating our own.
- Make resources available to establish multi-disciplined teams and integration of disciplines by strongly supporting and rewarding institutional re-structuring.
- Set a unifying theme. Materials such as metals, alloys, ceramics, glasses, cements, concrete, polymers/plastics, composites and semi-conductors are materials that underpin modern manufacturing industry. A materials platform for national nanotechnology activity (Figure 5) supports existing capability (eg. minerals processing) and emerging manufacturing strengths (eg. biomaterials in medical prosthetics). Defined widely it includes, for example, aspects of silicon-doping to be used as materials essential to a quantum computer, or materials as biocompatible composites in implantable biosensors.

Figure 5: A focus on Materials as a Way Forward for Nanotechnology Investment



Appendix 1: Stakeholder Map and Limited Contact Information

Summary - This Appendix provides a simple categorisation of the many persons and entities that may have an interest in nanotechnology, as a high-level map. This serves to identify categories and examples, and does not attempt to exhaustively list every possible example.

There are overlaps between these stakeholders in the categorisation presented. The most important of all stakeholders in the context of this document are the companies and industries that could benefit from knowing more about the field and their uptake of appropriate nano-scale technologies.

This layout indicates some strengths and weaknesses across the existing stakeholders and how various gaps are being closed by better networking.

The Appendix also provides examples of recent reports on nanotechnology, and lists internet addresses that may be useful to those seeking to familarise themselves with the field and the various stakeholders, some of whom may be known and others not known to readers, depending on where they are positioned in industry or research.

The information includes both Australian and international sites, as the readership of this document may be either domestic or overseas.

The following section is a generalised map of key stakeholders with direct or indirect interests in nanotechnology.

It is not comprehensive of all possible stakeholders, in some instances only listing groups or areas of stakeholder interest.

The section simply lists weblinks to the specific public and private entities that are interested in nanotechnology.

Furthermore, some sites that are well known to the Australian research and industrial community are included here for the benefit of international readers.

The Stakeholders are divided into five non-exclusive and often times overlapping groups.

Overview of Stakeholder "Map" - Five Linked Groups

Group 1 - Public Sector and Related R&D and "Imaginings"

This stakeholder category includes:

- Universities, research centres and their related technology transfer entities
- Medical research institutes and associated R&D centres
- Cooperative Research Centres, ARC Special Centres or Centres of Excellence
- CSIRO, DSTO, ANSTO, Rural R&D Corporations
- Related public relations and lobby groups eg CRC Association

Group 2 - Private Sector Industry Companies and Advisory

This stakeholder category includes:

- Corporates
- Private and public listed Australian Companies (Australian owned)
- As above – Australian based with multi-national ownership

Advisory to Corporates:

- Industry professional advisory (eg legal, IP/patent, capital raising, IP/valuation, taxation, marketing and public relations)

Advanced technology investors:

- VC and related risk investment funds, private-high net worth investors, corporate investment funds

Group 5 - National Awareness and Networks

This stakeholder category includes:

- Industry related networks (eg industry and professional associations, networks, conference organisers and providers, related internet sites)
- Media eg radio/TV and press – especially business, science and technology press, investment advisory press
- Industry/market press and publications eg journals and periodicals
- Professional and other public interest eg education

Group 3 - Public Sector Policy, Funding and Advisory

This stakeholder category includes:

- Commonwealth Department of Education, Science and Training
- Australian Research Council
- Department of Health
- National Health and Medical Research Council
- Department of Industry, Tourism and Resources
- AusIndustry
- Office of Chief Scientist
- National Standards Commission
- IP Australia
- Science Technology and Advisory Bodies (eg PMSEIC)
- Others eg PDF Board, IR&D Board, Biotechnology Australia

Group 4 - Nanotech Networks Global Links and Investment

This stakeholder category includes:

Australian public sector related -

- Invest Australia
- State government regional development and investment attraction

International:

- International nanotechnology groups/sites
- US, APEC, EU and Framework Support programs
- Australia-Other Chambers of Commerce (eg Other = US, German etc)
- Regional links eg Sister-City links eg Melbourne/Boston
- Links via attendance at international events and trade-fairs

Website details regarding nanotechnology stakeholders

The following section provides tables of some the relevant websites associated with each Stakeholder group.

These tables are not exhaustive and represent only a sample of the stakeholders in each group.

Group 1 - Public Sector and Related R&D

The following table presents a list of University Departments and Research Institutes, CRC, ARC and Centres of Excellence who have demonstrated a particular interest in the development of nanotechnology. Other general public bodies, beyond the currently active "Imaginings", who could possibly be interested in the benefits of nanotechnology and could have the potential research resources to fulfil this focus are also mentioned.

http://www.atse.org.au/Default.htm	Australian Academy of Technological Sciences and Engineering
http://www.photonics.com.au	Australian Photonics CRC
http://www.ansto.gov.au	Australian Nuclear Science and Technology Organisation
http://rsc.anu.edu.au	Australian National University, Research School of Chemistry
http://www.rsphysse.anu.edu.au	Australian National University, Department of Electronic Materials Engineering, Research School of Physical Sciences and Engineering
http://laserspark.anu.edu.au/~kgb111/	Australian National University, Atom Manipulation Project, Research School of Physical Sciences and Engineering
http://rsphysse.anu.edu.au/~vsj110/vsj.html	Australian National University, Department of Applied Mathematics, Research School of Physical Sciences and Engineering
http://www.pfpc.unimelb.edu.au/	ARC Special Research Centre for Particulate Fluids Processing
http://www.iwri.unisa.edu.au	ARC Special Research Centre for Particle and Material Interface
http://www.qcaustralia.org	ARC Special Research Centre for Quantum Computer Technology
http://www.eleceng.adelaide.edu.au	Centre for Biomedical Engineering, Adelaide University
http://www.biotechnology.gov.au/Industry_Research/CoE/coe.asp	Centre of Excellence for Biotechnology
http://www.noie.gov.au/projects/IndDev/CofE/index.htm	Centre of Excellence for Information and Communication Technology
http://acsys.anu.edu.au/	CRC for Advanced Computer Systems
http://www.bionicear.com.au/crc	CRC for Cochlear Implant and Hearing Aid Innovation
http://www.foodpack.crc.org.au	CRC for International Food Manufacture and Packaging Science
http://www.microtechnologycrc.com	CRC for Microtechnology
http://www.crcp.com.au	CRC for Polymers
http://www.dbce.csiro.au/	CSIRO Division of Building, Construction and Engineering
http://www.det.csiro.au/energy.html	CSIRO Energy Technology
http://www.dbce.csiro.au/	CSIRO Health Sciences and Nutrition
http://www.cmst.csiro.au/material/particle_processing/overview.htm	CSIRO Manufacturing Science & Technology
http://www.minerals.csiro.au	CSIRO Minerals

http://www.molsci.csiro.au	CSIRO Molecular Science
http://www.tip.csiro.au	CSIRO Telecommunications and Industrial Physics
http:// www.tft.csiro.au	CSIRO Textile & Fibre Technology
http://chemistry.curtin.edu.au/ AND http://www.physics.curtin.edu.au/	Curtin University of Technology, School of Applied Chemistry
http://www.drdc.aust.com/	Dairy Research and Development Corporation
http://203.36.224.190/cgi-bin/dsto/extinl.pl?233	Defence Science and Technology Organisation
http://www.socpes.flinders.edu.au/	Flinders University of South Australia, Faculty of Science and Engineering
http://www.sct.gu.edu.au/~sctsang/	Griffith University, School of Science
	Institute of Bio-Engineering and Nanotechnology, Queensland
http://www.mateng.asn.au	Institute of Materials Engineering Australasia (IMEA)
http://www.monash.edu.au/mateng/camt.html	Monash University, Centre for Advanced Materials Technology
http://www.ecse.monash.edu.au	Monash University, Department of Electrical and Computer Systems Engineering
http://www.nanoparticle.com & www.nanoprobe.org	University of Melbourne, School of Chemistry
http://www.sci.qut.edu.au/physci/cidc/materials /RLF/Default.htm	Queensland University of Technology
http://www.rirdc.gov.au/links.html and http://www.affa.gov.au	Rural Industry Research and Development Corporations
http://www.physics.adelaide.edu.au/cssm/index.html	Special research centre for Subatomic Matter
http://www.swin.edu.au/iris/	Swinburne University of Technology, Industrial Research Institute
http://srv.emunit.unsw.edu.au/	University of New South Wales, Electron Microscope Unit
http://www.phys.unsw.edu.au/	The University of New South Wales, School of Physics
http://www.uq.edu.au/nanoworld	University of Queensland, The Centre for Microscopy and Microanalysis
http://www.chemistry.uq.edu.au/nbc	University of Queensland, The Centre for Nanotechnology and Biomaterials
http://www.physics.uq.edu.au	University of Queensland, The Department of Physics (Experimental Soft Condensed Matter Group)
http://www.rheology.uq.edu.au	University of Queensland, The Materials Characterisation and Processing Centre
http://nanomac.uq.edu.au	University of Queensland, The Nanomaterials Centre,
http://www.iwri.unisa.edu.au	University of South Australia, Ian Wark Research Institute
http://www.phys.uts.edu.au/Solar/ and http://www.phys.uts.edu.au	University of Technology, Sydney, Applied Physics and Centre of Materials Technology
http://www.science.uts.edu.au/cmf/ms/index.html	University of Technology, Sydney, Department of Chemistry, Materials and Forensic Science
http://www.uts.edu.au/science/physics	University of Technology, Sydney, The Institute of Nanoscale Technology
http://www.uts.edu.au/~ravir	University of Technology, Sydney, Faculty of Engineering
http://cmm.uwa.edu.au	University of Western Australia, Centre for Microscopy and Microanalysis
http://www.physics.uwa.edu.au/~stamps	University of Western Australia, Department of Physics

Group 2 - Private Sector Industry

This table provides a selection of private and public listed Australian companies that are involved in the exploitation of developments in the nanotechnology arena. These companies cover a wide cross section of Australian industry and are at varying stages of commercialisation.

All mentioned companies are registered on the Australian Security and Investment Commission (http://www.asic.gov.au).

The weblinks to a few entities involved with venture capital support have also been listed at the bottom of the table. Other service providers such as patent attorneys and other professional services providers (being part of Group 2) are not included here.

http://www.ant-powders.com/	Advanced Nano Technology Pty Ltd
http://www.agen.com.au; www.agenix.net/	AGEN Biomedical Ltd
http://www.ambri.com.au	Ambri Pty Ltd
http://www.amira.com.au	AMIRA International
http://aortechbio.com	AorTech Biomaterials
http://www.artimech.com.au	Artimech Pty. Ltd.
http://www.avcal.com.au	Australian Venture Capital Association Ltd
http://boeing .com.au	Boeing Australia
http://www.bottlemagic.com.au	Bottle Magic Pty Ltd
http://www.bwfoundry.com	Bandwidth Foundry Pty Ltd
http://www.cap-xx.com	Cap XX Pty Ltd
http://www.dnanotech.com	Dendritic Nanotechnologies Ltd
http://www.fujitsu.com.au	Fujitsu Australasia Pty Ltd
02 9772 8284	Hawker de Havilland Ltd
http://www.lucnet.com.au	Lucent Technologies - Bell Laboratory Innovations
-	NanoChem Limited and NanoChem Research Pty Ltd
-	Nanoquest Pty Ltd
http://www.orica.com.au/business/cor/2001/wc or00002.nsf/headingpagesdisplay/home	Orica Australia Pty Ltd
http://www.panbio.com.au	Panbio Ltd
-	Pan Pacific Pharmaceuticals
-	Pro-M Technologies Pty Ltd
http://www.psivida.com.au/collaboration.html	PSiVida and BioSilicon
http://www.quantum-pi.com	Quantum Precise Instruments Pty Ltd
http://www.redfernpolymer.com.au	Redfern Polymer Optics Pty Ltd
http:// www.surebeamsafe.com	SureBeam Australia Pty Ltd
http:// www.starpharma.com	The Starpharma Group Ltd
http://www.innovationgroup.com.au	The Innovation Group Pty Ltd
-	Very Small Particle Company Pty Ltd
http://www.avcal.com.au/	Australian Venture Capital Assn Ltd (AVCAL)
http://www.v-capital.com.au/	Venture Capital Market Place
http://www.vcmarketplace.com/vcdirectory.htm	Venture Capital Directory

Group 3 - Public Sector Policy, Funding and Advisory

This table provides overseas readership guide to the public groups that are involved in general science and technology activity in Australia. The group encompasses some major Commonwealth Departments and bodies who provide services and support to the general scientific research community and industry groups by the provision of funding and advice, or being the administrative body responsible for relevant public policies. Deeper research would be required to investigate whether they are actively involved in specific nanotechnology related projects.

http://www.affa.gov.au	Agriculture, Fisheries and Forestry Australia
http://www.ausindustry.gov.au	AusIndustry
http://www.antdiv.gov.au	Australian Antarctic Division
http://www.health.gov.au	Australian Department of Health and Ageing
http://www.agso.gov.au	Australian Geological Survey Organisation (AGSO)
http://www.aims.gov.au	Australian Institute of Marine Science (AIMS)
http://www.anzfa.gov.au	Australian and New Zealand Food Authority
http://www.ansto.gov.au	Australian Nuclear Science and Technology Organisation (ANSTO)
http://www.arc.gov.au	Australian Research Council
http://www.austrade.gov.au	Australian Trade Commission
http://backingaus.innovation.gov.au/	Backing Australia's Ability
http://www.isr.gov.au/ba	Biotechnology Australia
http://www.bom.gov.au	Bureau of Meteorology
http://www.detya.gov.au/	Commonwealth Department of Education, Science and Training
http://www.csiro.au	Commonwealth Scientific and Industrial Research Organisation
http://www.isr.gov.au/crc/index.html	Cooperative Research Centres
http://www.dest.gov.au/science/ccst/	Coordination Committee on Science and Technology
http://www.dsto.defence.gov.au	Defence Science and Technology Organisation
http://www.industry.gov.au/	Department of Industry, Tourism and Resources
http://www.gbrmpa.gov.au	Great Barrier Reef Marine Park Authority (GBRMPA)
http://www.health.gov.au/ogtr/about/index.htm	Interim Office of Gene Technology Regulator
http://www.ipaustralia.gov.au	IP Australia
http://www.investaustralia.gov.au	Invest Australia
http://www.nanotechnology.gov.au/	Nanotechnology in Australia
http://health.gov.au/nhmrc/	National Health and Medical Research Council (NHMRC)
http://www.nsc.gov.au	National Standards Commission
http://www.dpi.qld.gov.au/ocs/	Office of Chief Scientist
http://www.dest.gov.au/science/pmseic/	Prime Minister's Science and, Engineering and Innovation Council
http://www.affa.gov.au	Rural R&D Corporations
http://www.dest.gov.au/science/index.htm	Science and Technology Advisory Bodies
http://www.sta.com.au	Sustainable Technologies International

Group 4 - Nanotechnology Networks Global Links and Investment

The following tables are just a modest collection of international groups involved specially in the development of nanotechnology. This section demonstrates to the Australian readership the depth and breadth to which nanotechnology has penetrated a variety of industries over a number of countries. International activity in relation to exploitation of nanotechnology is relatively mature compared with Australia.

US sites

http://www.nano.gov	US National Nanotechnology Initiative
http://www.nsf.gov/home/crssprgm/nano/start.htm	US National Science Foundation Nanotechnology site
http://www.nas.nasa.gov/Groups/SciTech/index.html	Nanotechnology at NASA
http://www.imm.org	Institute for Molecular Manufacturing
http://www.foresight.org	Foresight Institute
http://nanodot.org/	Foresight Institute, news and discussion
http://www.homestead.com/nanotechind/companies.html	Companies involved in nanotechnology (mostly in US)
http://www.homestead.com/nanotechind/academic.html	Academic nanotechnology groups, research and labs (mostly in US)
http://www.homestead.com/nanotechind/government.html	Government nanotechnology links (mostly US)
http://www.homestead.com/nanotechind/organizations.html	Organisations involved in nanotechnology (mostly US)
http://www.zyvex.com/nano/	Nanotechnology at Xerox
http://www.research.ibm.com/nanoscience	Nanoscale science at IBM
http://www.argonide.com	Argonide Nanometal Technologies
http://66.28.45.185/cni/index.cfm	Carbon Nanotechnologies, Inc.
http://www.bccresearch.com	Business Communications Company, Inc.
http://nanozine.com	Nanotechnology Magazine
http://www.nanometrics.com	Nanometrics, Incorporated
http://www.nanobusiness.org	Nanobusiness Alliance
http://www.altairtechnologies.com	Altair Technologies Inc
http://www.nanosig.org	Nano Sig

EU sites

http://www.nanoforum.org	Information on European Nanoscience and technology
http://nanocentre.ncl.ac.uk	Univ. of Newcastle upon Tyne, Centre for Nanoscale Science & Technology
http://www.oxonica.co.uk.	Nanocrystalline materials (Univ. of Oxford spin-off)
http://www.nano.org.uk/	The Institute of Nanotechnology UK
http://www.nanonet.de/english/	German Government Nanotechnology site
http://www.vdivde-it.de/mstnews/	International newsletter on Microsystems
http://apte.net/nano	APTE Association
http://www.cordis.lu/nanotechnology	CORDIS - Highlights elements of European nanotechnology community

Asian sites

http://www.atip.org/NANO	Information on Asian Nanotechnology
http://www.meti.go.jp/english/	Ministry of Economy, Trade and Industry, Japan

Group 5 - National Awareness and Networks

1) Existing Microtechnology and Proposed Nanotechnology Networks

These networks are directly related to the work encompassed by the Nanotechnology field. Although the last two are still in embryonic form they represent, or hope to represent, mainly research institutes and organisations and provide these groups with the intrastructure for collaboration and networking with other research groups and also industry alliances.

Name	Purpose	Contact
Australian Microelectronics Network Ltd (AMN)	AMN is a national not-for-profit development network aiming to expand the microelectronics industry. Their vision is to encourage a vibrant microelectronics design community with companies, governments and universities collaborating as a part of a technology development cluster. AMN aims to achieve this by facilitating access to affordable integrated circuit design software, fabrication and device testing facilities. With significant funding from the Department of Industry, Tourism and Resources, the campaign is to promote the cost, speed and reliability benefits of advanced micorelectronics targeted to Australian manufacturers.	**Chris Hanlon** Executive Director 1800 880 544
The Australian Nanotechnology Network	This network is being established to link for the first time, the various activities in nanotechnology around the country in science, education, industry, government, investment, international links and social implications of new technologies.	**Dr Vijoleta Braach-Maksvytis,** CSIRO vijoleta.braach-maksvytis@csiro.au
The Australian Nanotechnology Association	The ANA is expected to be launched in Sept 2002 and will consist of R&D providers and Australia's nanotechnology companies, to serve as an independent source of advice to various government and other bodies on relevant issues. One purpose is to act as the peak body for Australian nanotechnology industry and to facilitate the commercialisation of Australian nanotechnology in the international marketplace. It expected to become part of the above Australian Nanotechnology Network once established.	**Dr Terry Turney,** CSIRO terry.turney@csiro.au

2) Existing Industry Focused Networks

The following table provides an example of some of the existing organisations and associations that are currently available to various Australian industry groups. This table demonstrates the wide spectrum of disciplines and industries these associations and organisations support.

By way of raising industry awareness of nanotechnology, to lesser or greater extent, all the following organisations have some existing or latent interest in the field.

Acronym	Full Title	Website
ABA	AusBiotech - (was Australian Biotechnology Association)	http://www.ausbiotech.org/
MDN	Medical Device Network	http://www.ausbiotech.org
ABL	Australian Business Ltd	http://www.australianbusiness.com.au
AEEMA	Australian Electrical & Electronic Manufacturers Association	http://www.aeema.asn.au
AFGC	Australian Food and Grocery Council	http://www.afgc.org.au
AIIA	Australian Information Industry Association	http://www.aiia.com.au
AIIE	Australian Industry Innovation Exchange	http://www.aigroup.asn.au/
AIP	Australian Institute of Physics	http://www.aip.org.au
APAC	Australian Partnership for Advanced Computing	http://www.nf.apac.edu.au/
APMA	Australian Pharmaceutical Manufacturers Association Inc	http://www.apma.com.au
AMIRA	Australian Minerals Industries Research Association Ltd	http://www.amira.com.au
ARAA	Australian Robotics & Automation Association	http://www.araa.asn.au
EIA	Electronics Industry Association	http://www.eiaa.asn.au
FAST	Federation of Australian Scientific and Technological Societies	http://www.fasts.org
IMEA	Institute of Materials Engineering Australasia Ltd	http://www.mateng.asn.au/
IEAust	Institution of Engineers Australia	http://www.ieaust.org.au
MIAA	Medical Industry Association of Australia	http://www.miaa.org.au
PACIA	Plastics & Chemicals Industries Association Inc	http://www.pacia.org.au
SIA	Science Industry of Australia	http://www.scienceindustry.com.au
TSA	Telecommunications Society	http://www.tsa.org.au
WMAA	Waste Management Association of Australia	http://www.wmaa.asn.au
WTIA	Welding Technology Institute of Australia	http://www.wtia.com.au

3) Existing General International and Domestic Industry Support Networks

Other support networks that are not directly aligned with specific industry sectors are also available in Australia. These can be general innovation groups that provide support directly to technology based small and medium sized start up companies. Alternatively, they may be non-specific industry support networks that are business-based alliances with links to other countries. These groups include various Chambers of Commerce who have relationships with Australia.

A small selection is listed below.

http://www.amcham.com.au	American Chamber of Commerce in Australia
http://www.austarab.com.au	Australian Arab Chamber of Commerce and Industry
http://www.acci.as.au	Australian Chamber of Commerce and Industry
http://www.aigroup.asn.au/	The Australian Industry Group - The Innovation Xchange
http://www.techshowcase.nsw.gov.au/	Australian Technology Showcase
http://austcham.org	China-Australia Chamber of Commerce
http://members.iinet.net.au/~italcham/	Italian Chamber of Commerce, Australia
http://www.germany.org.au/	German Australian Chamber of Commerce
http://www.swedelink.com.au/	Swedish Australian Chamber of Commerce
http://www.sacci.com.au	Swiss Australian Chamber of Commerce and Industry

4) Other General Network Tools

The following weblinks are to Australian tools, groups and information centres that provide support to the general businesses that require services in the way of product or marketing development. Alternatively, some also assist to establish and grow strategic networks or alliances.

http://www.biomedoz.com.au	Biomed Oz
http://www.biotechweb.net.au	Biotech Web
http://www.industrysearch.com.au	Industry.Search
http://www.iso.net.au	Isonet Tool Kit Ltd
http://www.pd-net.net/pdnet	PD-Net

5) Media and other Publication Material

The following tables are just small number of examples illustrating the extent to which nanotechnology has already been exposed to the public through the general media via television and the press.

Specific publications exclusively dedicated to nanotechnology, and general science and technology journals and periodicals that have featured nanotechnology as a central theme have also been included.

a) General Media and Media Releases

Relevant Body/Company	Nanotechnology	Source
Australian Broadcasting Corporation	General	http://www.abc.net.au/science/
Catalyst	Dendritic Nanotechnologies Pty Ltd	Catalyst ABC, 15 March 2002, 8pm
CSIRO, Manufacturing Science and Technology	Membrane technology to filter and separate various nanoparticles i.e. gases and vapours	http://www.csiro.au/page.asp?type=mediaRelease&id=Nanospace
CSIRO, Telecommunications and Industrial Physics	Australia joins the tiny revolution	http://www.its.csiro.au/index.asp?type=mediaRelease&id=Prnanotechnology&xml=relatedMediaReleases;count=7;start=49&style=mediaRelease
CSIRO, Textile and Fibre Technology	Clothes that know when you've been sleeping	http://www.csiro.au/index.asp?type=mediaRelease&id=prsmarttextiles
Lucent Technologies Australia	Organic Nanotransistors	http://www.lucent.com.au/intl/au/en/press/011109.html
National Nanotechnology Investment in the FY 2002 Budget Request by the President of USA	General	http://www.nano.gov/2002budget.html

b) Nanotechnology Publications

Relevant Body/Company	Nanotechnology	Source
CMP Cientifica, November 2001	General	http://www.cientifica.com
Department of Industry, Tourism and Resources	Scoping Study into Nanotechnology Diffusion, January 2002	http://www.nanotechnology.gov.au/index.cfm?area=browse&id=8
Department of Industry, Tourism and Resources	Nanotechnology in Australian Industry: Proceedings and Outcomes Report of Workshop in Nanotechnology, March 2001	http://www.nanotechnology.gov.au/index.cfm?area=browse&id=8
Invest Australia	General	http://www.investaustralia.gov.au/Industry_Sectors/IT_T/NANOTECH.pdf.
Invest Australia	Marketing Document: From Little Things Big Things Grow	http://www.nanotechnology.gov.au/index.cfm?area=browse&id=8
In Realis	A Critical Investors Guide to Nanotechnology, February 2002	http://www.inrealis.com/nano.htm
Nanobusiness Alliance News	Nanotechnology in Australia	http://www.nanobusiness.org/whats_new.htm
Nanotech Syndication published by ICA Syndicate	Publication on Nanotechnology, first issue May 2002	http://www.icasyndicate.com/ica_nanosyn_sub.html

c) Journals and Periodicals

Publication	Nanotechnology	Source
Australian Biotechnology News	Playtime is over, now 'atomic Lego' goes to work	http://www.biotechnews.com.au May 17, 2002
Australia Venture Capital Journal	New nanotechnology newsletter for investors	Page 20, May 2002
Australia Venture Capital Journal	Nanotechnology Investment: at the Cross Roads	Page 21 - 22, May 2002
Business Review Weekly	Dendrimer Platform Technology	http://www.brw.com.au/stories/20020314/13667.asp Or BRW, page 40 March 14-20 2002
Business Review Weekly	Innovation: the atomic revolution	BRW, pg 68 April 18-23 2002
Foresight Update	Publication prepared by the Foresight Institute	http://www.foresight.org/News/index.html
Foresight Website; News and Distribution of Coming Technologies	Finding a rational approach to nanotech opportunities and dangers	http://nanodot.org/article.pl?sid=01/12/07/1812225&mode=thread&threshold=.
Scientific American	Special issue - Nanotech The Science of the Small Get Down to Business	September 2001 http://www.sciam.com

APPENDIX 2: Summary of Relative Strengths and Opportunities of Linkages within the "Stakeholder Map" and Actions to Address these Circumstances

The following indicates existing strengths and weaknesses across the broad stakeholder groups. This is a high level view. Impacts are different depending on the perspective of any sub-group or specialist interest within the stakeholders.

Public Sector and Related

Relative Strength	Sector has bulk of R&D capability; growing educational awareness eg new undergraduate programs in nanotech; early evidence of spin-off companies, moderately well connected at R&D/academic levels nationally and internationally eg evidence of international staff/student exchange; new nano-ultrastructural analysis centres established eg MNRF
Relative Weakness and Opportunity	Lack of effective integration of multidisciplinary capability and infrastructure within organisations (eg funding and resource impediments). In many instances, too difficult to find or recruit partners such as high-tech companies in private sector with early interest in field (eg R&D too early stage). The evidence for this includes eg. inability to found CRCs in nanotech (though some existing CRCs have nanotech related projects). Too few products/applications being prepared at "information memoranda" standards eg lack of quality investment proposals. Insufficient opportunities to prepare and present such proposals eg at arranged domestic nano-partnering meetings.

Private Sector Industry and Advisory

Relative Strength	Few early start-ups are winning publicity; other nanotech-related activities exist but not promoted as such by companies
Relative Weakness and Opportunity	From company and industry perspective - either not aware or, if aware, do not adequately understand nano-concepts nor benefits, typically because examples are too conceptual (or presented as such) rather than being product/applications specific. Australian early stage and advanced technology investors see area as too risky and too far from tangible market outcomes. Patent attorneys will need to up-skill knowledge to serve new specialist aspects of the nanotech field. Estimation of IP value and market worth difficult to meaningfully assess at this stage, heightens stand-off by industry and investors.

National Awareness and Networks

Relative Strength	Increasing number of business/science-press publications, broadcasts and related featuring aspects of nanotechnology or related Proposed conferences and meetings covering aspects of nanotechnology. Proposals for national nanotechnology network - gathering momentum.
Relative Weakness	Few flag-ship companies or products or high profile "success stories" that inspire industry and investors - mostly stories dwell on future potential of field. Leadership commentators and communicators predominantly come from "science-push" sector - tends to undermine industrial credibility No working models of nanotech-related products eg exhibitions or displays of national capability/products

Public Sector - Policy, Funding and Advisory

Relative Strength	Established national nanotechnology www portal. Moderate recognition of nanotechnology by key agencies eg ARC thematic funding priorities. Limited coordination across Commonwealth Departments and awareness raising at PMSEIC level.
Relative Weakness and Opportunity	To date limited evidence of national coordination of policy that includes Commonwealth and States and all major stakeholder agencies. No flag-ship initiative eg such as national funding initiative; any competitive funding comparable to Biotechnology Centre of Excellence or existence of sub-agency such as Biotechnology Australia. No evidence of active inter-departmental advisory group or specialist industry advisory group reporting to PMSEIC etc

International Alliances and Networks - Global Links and Investment Attraction

Relative Strength	Some initial activity in promotion of Australian nanotech capability internationally with the assistance of Invest Australia Some evidence of company and/or institutional networking and alliances at international level; eg joint ventures and research cooperatives etc. Small specialist groups eg from academic sector have been able to attend international meetings eg APEC, to assess other work and promote Australian capability.
Relative Weakness and Opportunity	Australia has few nanotech ambassadors eg world respected authorities in the field. Little or no mobilisation of national capability or promotion by alignment or integration with international nanotech-networks. Little knowledge, expertise or even interest among locally-based multi-nationals in pushing Australian nano-capability - these tend to be R&D/technology investment decisions made in head-offices off-shore.

Australian Nanotechnology Networks

Relative Strength	Specifically targeted to researcher and industry groups directly involved in the development and exploitation of achievements in nanotechnology. This defined group will allow the provision of tailored support, infrastructure and resources that are widely needed in these largely fledgling sectors.
Relative Weakness and Opportunity	Nanotechnology Networks are in embryonic stage and will require time, resources and energy from mainly key individuals. A huge amount of dedication is required to commit to the cause and generate the support and momentum required to establish functional and active networks.