Small Scale Technologies: Directions for Victoria

Final Report

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Executive Summary

Small scale technologies are already having a significant economic and social impact. Over the next two decades they will have profound effects on industrial products and processes, on the lives of individuals and on the nature of human society. As the next major wave of global technological change, they offer vast potential benefits but carry serious economic, social and ethical risks. It is important that Victoria acts now to share in the potential benefits of small scale technologies and to understand and respond to the risks involved.

We use the phrase 'small scale technologies' to refer to technologies with feature sizes less than 1000 nanometers, where a nanometer is one millionth of a millimetre. In other words, they are technologies with feature sizes less than one thousandth of a millimetre. The term thus covers both *micro technologies*, operating down to about 100 nanometers, and *nano technologies*, operating at or about the nanometer scale. Technologies at both levels are already being used in industry, often in combination with one another. Micro technologies are currently much more important in industrial applications. But those at the nano scale will become increasingly dominant in a wide variety of industries over the next two decades. They will also have the most dramatic implications, as new properties of matter emerge at the very small scale.

These facts have been recognised by governments around the world, and support programs amounting to some US$3 billion are in place in 2003. Substantial commitments have been made by a number of countries in East Asia as well as in North America and Europe, and this is the first technological revolution in which Asian countries have been participants at a foundational stage. Much of this support has been in terms of basic science, and in particular in the scientific foundations of nano technologies.

This report examines the implications of small scale technologies for industries and firms in Victoria, in the context of the broader drivers of change in those industries. It shows that these technologies will have a pervasive impact on the competitive position of Victorian firms in a wide range of industries, from health and food to transport, energy and the environmental industries. There is little doubt that developing high-level capability in small scale technologies will become increasingly central to the competitiveness of many industries over the next decade, and indeed to the survival of many firms. It will also be necessary to maximize the welfare of Victorians in areas such as health, the environment and security.

The State has some important scientific capabilities in relevant areas, and valuable nodes of expertise in the development and application of small scale technologies for commercial use. But there is still only limited awareness of the potentially revolutionary role of these technologies in the business sector and in the community at large. Victoria can be only a niche player in terms of scientific excellence, but it can play a significant role in the application of small scale technologies in many areas of human life.

In our view, the central challenge is to use emerging small scale technologies to protect and enhance the competitiveness of existing industries, to encourage new and growing local and overseas firms and to generate broader social benefits for the Victorian community. Comprehensive leadership by the Government in helping Victorians to address this challenge is appropriate at this time, before the opportunity to establish a leading position in the technologies and their applications is lost.

The central objective of Victorian policy in this area should be to make the State a leading centre for the commercial development and application of small scale technologies by firms, public agencies and other organisations, in the context of sustained and shared reflection on the social and ethical issues involved. Activities to achieve this objective should be directed at small scale technologies generally, and not just at nano technologies, and at the commercial and social application of these technologies.

What is needed is a coordinated program of action - involving industry, academia and government - that is sustained over the long term. For this reason it is proposed that the Government establish, in conjunction with industry and academia, a new peak body – Small Scale Technologies Victoria – to provide the leadership necessary to make Victoria a leading centre for the commercial development and application of small scale technologies. Coordinated action in six areas is necessary:

- *Facilitating Infrastructure*: working with firms and research groups, and international experts, to plan and implement the basic infrastructure required for the application of small scale technologies, and to review that infrastructure on a regular basis.
- *Raising Awareness and Demonstrating Applications*: implementing programs to raise awareness in firms and in the community about the implications of small scale technologies, for example by funding demonstration projects.
- *Building the Skills Base*: bringing together industry, universities and TAFE colleges to identify current or emerging gaps in Victoria's skill base for the application of small scale technologies, and to design and implement appropriate programs.

- *Encouraging Commercial Applications*: encouraging commercial applications of small scale technologies, through creation of Applications Development Consortia and in other ways.
- *Facilitating Alliances and Networks*: assisting local firms and research institutions to enter into alliances and networks with firms and institutions operating elsewhere in Australia, and in the USA, Europe and East Asia.
- *Strengthening Social and Ethical Reflection*: strengthening the capacity of the Victorian community to address, in a sustained and considered fashion, the social and ethical issues raised by small scale technologies.

Much is already being done to build the necessary infrastructure in Victoria, through the creation of MiniFAB, NanoVic and Bio21, the construction of the Australian Synchrotron and the activities of the universities, CSIRO and the Cooperative Research Centres. However, much remains to be done to build adequate commercialisation infrastructure, for example in terms of facilities for the rapid design, development and prototyping of micro-devices and for measurement and testing at the micro and nano levels.

A detailed review of immediate infrastructure needs, drawing on both local and international expertise, should be an immediate priority. Our initial assessment is that an allocation of about $30 million over the next 2-3 years from the STI program should prove sufficient to meet those immediate needs, if the funds are carefully used to leverage matching funds from industry, the universities and the Australian Government.

The leadership and coordination role of Small Scale Technologies Victoria will be crucial to achieving the objective proposed here. Various legal structures are available for such a body, but four points are crucial. First, it must have a real tripartite presence, with high level and committed leaders from each of industry, academia and government actively involved. Second, it must have a long-term focus and role, with the stability of membership, public acceptance and assured funding necessary to pursue its objectives over a decade or more. Third, it must have continuing access to the best available expertise, both from within Australia and from other countries.

Finally, Small Scale Technologies Victoria must have sufficient assured funding to be seen by all parties, both here and abroad, as a serious player in pursuing its objectives, without ever being perceived as yet another granting body. Funding for this new peak body of about $20 million per annum, committed for five years in the first instance and renewable subject to review, would be significant in an international context and would provide a strong resource base to achieve the proposed objective.

1. Introduction

1.1 Understanding Small Scale Technologies

For many years scientists have been studying the properties of matter and living organisms at the molecular and atomic level, and firms have made use of knowledge of these properties to create commercial products and processes. Over the past two decades, however, it has become possible to manipulate atoms and molecules to create new materials, devices and processes, designed at the atomic level. At this very small scale, the characteristics of traditional materials change, as quantum effects and surface and other properties become dominant, so that quite new possibilities emerge. In the not too distant future, the growing application of new materials, devices and processes engineered at the very small scale will have a major impact on economic and social life, comparable to the present impact of information and communication technologies.

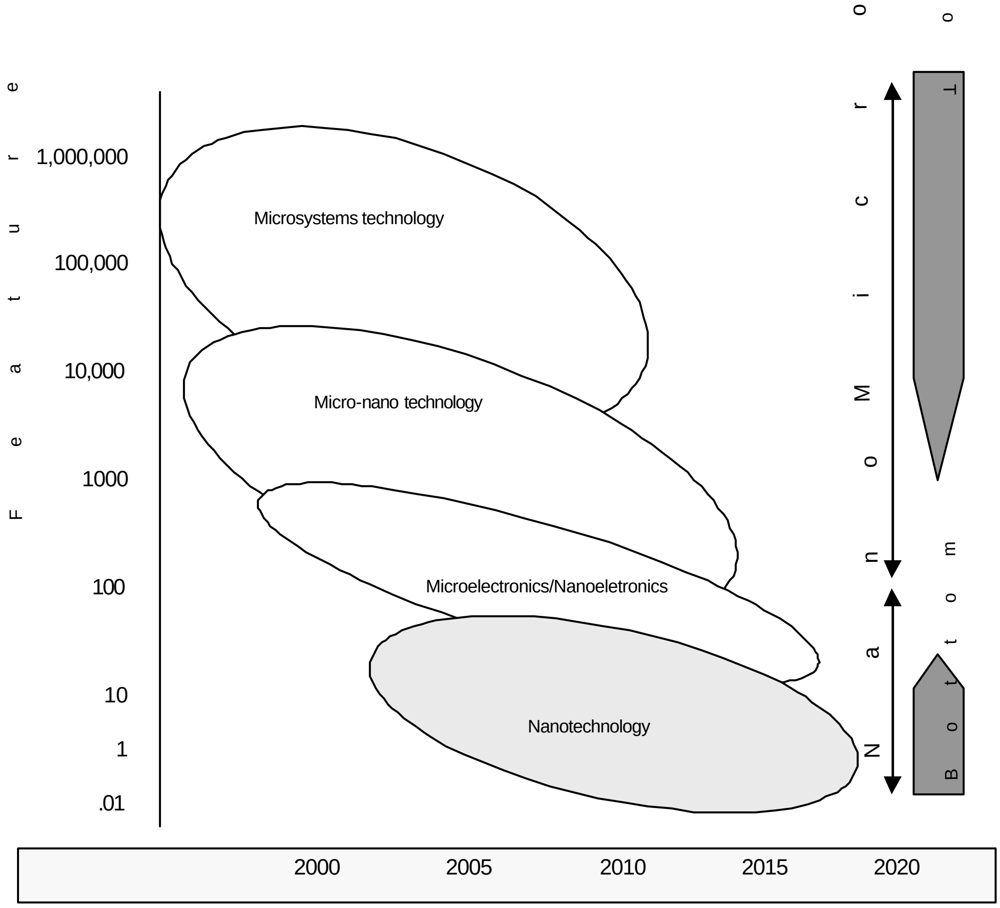
This report is about the likely impact of small scale technologies on Victoria, the opportunities and challenges that they present and the appropriate policy responses. Small scale technologies are defined simply as the application of knowledge about the small scale structure of matter and of living organisms to make new products and to develop new or improved processes. It is common to measure the scale of such technologies in terms of the nanometer, which is one millionth of a millimeter or 10-9 metres. Thus this definition is intended to cover, through the use of the term 'small scale', both micro technologies, operating at 100-1000 nanometers or 10-7 to 10-6 metres, and nano technologies, operating at the nano scale or below (10-8 to 10-10 metres). In practice, technologies at both the micro and the nano scale are already important, and many applications will involve a combination of both types of technology.

While this report covers both micro and nano technologies, over time there will be increasing use of applications at the very small scale. Nevertheless, it is important to focus on the broader concept of small scale technologies, to emphasise two key facts. One is that both micro and nano technologies are already being used in industry, often in combination with one another. The other is that, while micro technologies currently have wider use, technologies operating at the nano scale will become increasingly dominant in a wide variety of industries over the next two decades. This will not happen suddenly, but will occur steadily as the special properties of nano scale technologies are proven and as their costs of use fall. The evolutionary path of small scale technologies, including the increasing interlinking of micro and nano technologies and the imminent emergence of 'bottom up' nanotechnologies, is illustrated in Figure 1.

It is important to note also that this linking of micro and nano technologies is not just about producing small scale devices, products and processes, but that their use will transform many of the 'macro' products and processes of daily life. This transformation of macro products and processes is at the heart of the structural changes that small scale technologies will bring about, and highlights the need to respond to them.

In the Victorian Government's statement *Biotechnology: Strategic Development Plan for Victoria*, biotechnology is defined as the application of knowledge about living organisms and their components to make new products and to develop new industrial processes (DSRD 2001, p. 7). To the extent that biotechnology involves applications of small scale technologies, as it increasingly does, it is included in the coverage of this report. Our focus is on the use of micro and nano technologies to develop new products and processes, irrespective of the field of science from which they derive or the industry to which they are relevant. As in other areas, micro technologies are currently very important in biotechnology, but the field will be increasingly driven to the nano scale in the near future.

Figure 1. The Evolutionary Path of Small Scale Technologies



Source: Adapted from MANCEF (2002).

In addressing small scale technologies, we are concerned with the *application* of knowledge to create and exploit useful materials, devices and processes. Small scale technologies, while heavily reliant on the advance of scientific knowledge, are all about applying that knowledge for economic and social benefit. Australia in general, and Victoria in particular, has a high level of public expenditure on science, and major public institutions such as CSIRO and the universities have built up considerable excellence in many areas over a long period of time. The increasing application of small scale technologies will provide a way of leveraging this substantial investment for greater economic and social benefit. For this and other reasons it is vital to assess what these technologies mean for Victoria and to explore how we, as a community, should respond to the opportunities and challenges they present.

1.2 The Central Challenge

If Victoria is to prosper in the coming era of small scale technologies, a high quality scientific base in the underlying scientific disciplines will be vital. The Victorian Government has done much in recent years to help strengthen and modernise that base, through such measures as Bio21, the establishment of the National Synchrotron and through a range of STI initiatives, including the establishment of NanoVic. While scientific excellence is vital, it is not now the central challenge that we face. Rather, *the central challenge is to use emerging small scale technologies to protect and enhance the competitiveness of existing industries, to encourage new and growing local firms and to generate broader social benefits*. This is the challenge that we seek to address in this report.

There are many parallels between emerging small scale technologies and the information and communications technologies that have changed the world over the past two decades, and these parallels provide a salutary warning. Australia has become a sophisticated user of information and communications technologies over the past two decades. But, in spite of some relevant intellectual and business capabilities, Australia has not become a significant producer of new products in these areas, whether goods or services, nor has it been a creative force in the development of these technologies and of the industries that they have spawned. Thus output of information industry products in Australia is low and has recently been declining, overall employment in the information industries in low by world standards and Australia's deficit on information industries trade is high and rising (Houghton 2002, 2003).

Recent studies (Edquist et al. 2001) have argued that new product technologies create jobs, while new process technologies tend to be job destroying, with their benefits accruing through increases in productivity rather than through new employment opportunities. By failing to gain any serious position as a creator and producer of product technologies in the information industries, and becoming only a defensive adopter of process technologies to enhance efficiency, Australia has missed the creation of new streams of high value employment that have been associated with the information industries in some other countries.

This national experience helps to illuminate the central challenge that Victoria faces in relation to the small scale technology revolution. The central question is how Victoria can develop a serious position as an innovator in, and as a producer and user of, these technologies and the industries that they spawn and shape, so as to share in the wealth and employment creating aspects of this next technological revolution. This project is directed to providing some of the knowledge to assist firms and governments to address this challenge, and to make some recommendations to the Victorian Government about strategies. These policy recommendations are contained in Section 4, after we have reviewed global trends and issues in relation to small scale technologies (Section 2) and attempted a preliminary assessment Victorian capabilities and of the impact of these technologies on major Victorian industries (Section 3).

1.3 Small Scale Technologies and Industrial Change

Before proceeding on this path, however, it is important to situate small scale technologies within the broader range of factors driving change within key industries. These drivers include both factors common to most industries, related to global processes often referred to as the rise of the knowledge economy, and factors specific to individual industries.

Many industries face common drivers of change in the knowledge economy. Globalisation and the reduction of formal and informal barriers to trade are reducing the extent of protected markets. Excess capacity is sharpening competition, in many cases accentuated by the rise of developing countries such as China as real competitors. Consumer awareness is intensifying competition on price, performance and product quality. New technologies and increasing knowledge intensity are also driving increased competition in terms of the functionality and quality of existing products and the creation of new products. Growing environmental awareness is creating greater demands in terms of both environmentally sustainable products and production technologies. In short, firms in many industries face rapid change driven by increased global competition, technological change, increased consumer awareness and greater environmental requirements and regulation.

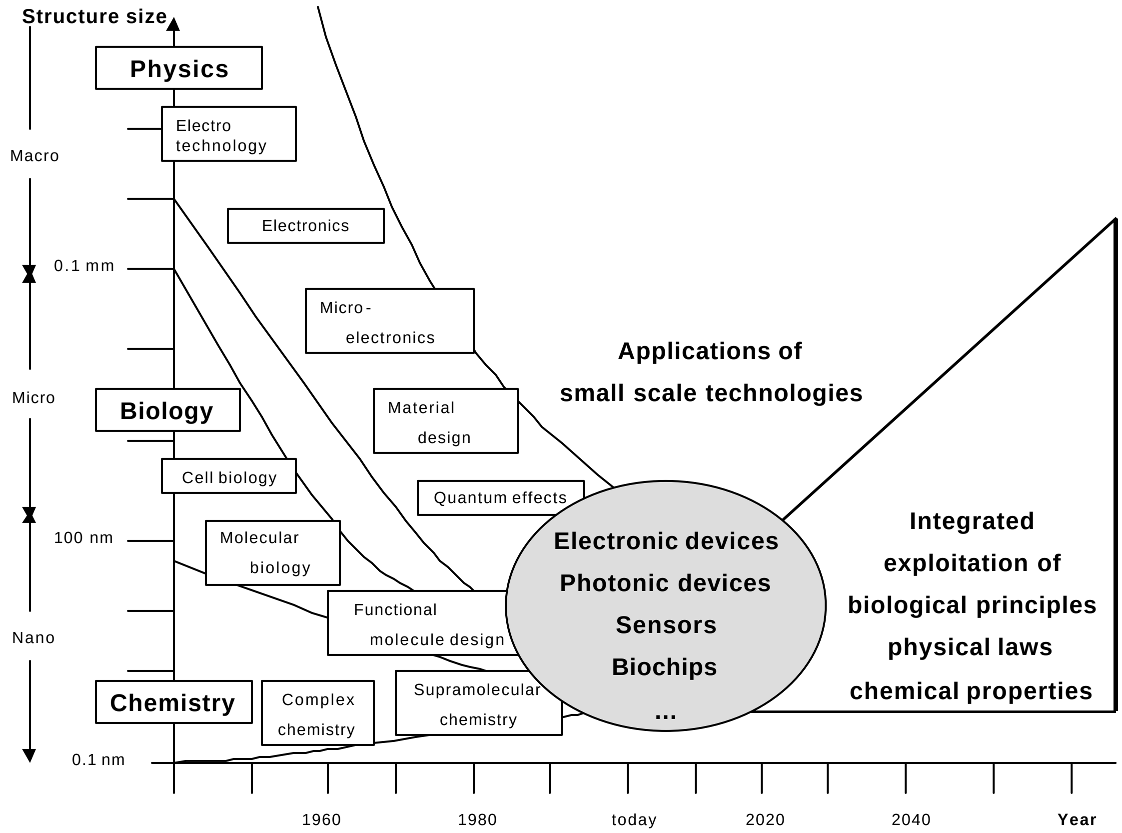
Within this broad context, there are of course many industry specific variants. For example, in a number of industries such as motor vehicles, pharmaceuticals and aerospace, the structure of the global industry is moving to a small number of ‘prime’ producers, which function in part as system integrators and product marketers, with a wide range of supplier firms distributed around the world. In such a case the requirements of the ‘primes’ and of the activities that they undertake (creating, producing and marketing new motor vehicle or aircraft models or discovering, testing, producing and marketing new drugs) become important drivers of change for other firms within the industry.

In Section 3 of this report we will attempt to sketch briefly the main drivers of change in each of the industries that we consider. In many cases, innovation becomes the key to improving competitiveness, and accelerating technological change is a central response to the competitive and other challenges that industries and firms face. Small scale technologies constitute at present only one of many aspects of this technological response, but they will become increasingly dominant in many industries over the next one to two decades. Now is the appropriate time to consider Victoria’s position in regard to these technologies – while their full impact is still in prospect rather than being a present reality, but before the opportunity to establish a leading position in the technologies and their applications is lost.

2. The Global Framework

The development and application of small scale technologies is a case study of globalisation at work, and any discussion of their impact on Victoria must be placed in this broader context. In this section we review very briefly the underlying scientific and technological trends, the emerging applications of these technologies, the response of governments around the world and some of social and ethical issues that arise.

Figure 2. Small Scale Technologies and the Convergence of Sciences



Source: Adapted from Bachmann (2001).

2.1 Underlying Scientific Trends

One underlying factor in the growth in nanotechnologies is the convergence of the various disciplines, illustrated in Figure 2. Thus, in *physics and related engineering disciplines*, the field of microelectronics has long been moving towards smaller feature sizes to achieve higher speeds and great functionality at reduced costs. This means that processors in computing systems will need nanometer line widths in the future to satisfy desired speeds.

Further, quantum effects are showing the way to alternatives to existing silicon technology for operation at nanometer scales. In *chemistry*, improved knowledge of complex systems has led to new catalyst, membrane, sensor and coating technologies which rely on the ability to tailor structures at atomic and molecular levels. In *biology*, living systems have sub-units with sizes between micron and nanometer scales and these can be combined with non-living materials to create new devices or can be used to create complex structures with desired properties.

More generally, a variety of disciplines are converging at the atomic or molecular level. This convergence of disciplines, and the development of technologies operating at a very small scale, has a range of synergistic effects. For example, scientific work becomes increasingly interdisciplinary, with knowledge and techniques from one area 'amplifying' work in other, overlapping areas. New research technologies operating at the micro or nano scale, such as scanning probe microscopes and micro-arrays, contribute significantly to further scientific progress, which in turn generates new technologies. This iterative process – the convergence of scientific research at the nano scale and the creation of new research technologies at that scale – seems certain to provide the central dynamic for scientific progress in the early decades of the 21st century.

In a scientific and technological sense this convergence at the nano scale is more than just a linear progression to a smaller scale, for at the nano scale quite new properties of materials and processes emerge. These new properties emerge from two main factors. The first is the dominance of quantum effects over Newtonian effects at the nano scale. The second arises from the fact that the ratio of surface area to volume rises as scale falls, so that surface properties and effects become much more important at the nano scale.

2.2 Some Current and Emerging Technologies

Technologies operating at the small scale are referred to by a variety of terms, such as microdevices, microsystems and microelectromechanical systems or MEMS. They have been in commercial use since the 1960s, and the first commercial products were small, light pressure sensors for the aerospace industry (MANCEF 2002). By the 1980s MEMS technologies were widely used in the automotive industry, in products such as pressure sensors and fuel injector nozzles. During the 1990s further technological advances, including the development of new manufacturing technologies and improved packaging solutions that allowed better integration of the components of a MEMS device, led to more applications. These have included hard-disk driveheads, ink-jet printers, heart pacemakers, in-vitro diagnostic devices and hearing aids. Table 1 reproduced from NEXUS (2002), shows the projected market in 2005 for both these and other current and emerging MEMS products.

Table 1. World Market for Current and Emerging MEMS Products

	Estimated global market, 2005 *(US$ millions)*
Current products	
Inkjet head	21,500
Read/write head	13,400
In vitro diagnostic	5,200
Heart pacemaker	4,700
Bio-chip	4,440
Optical mouse	3,400
Hearing aid	3,100
Pressure sensor	2,090
Gyroscope	770
Accelerometer	690
Magneto optical head	50
Flow sensor	360
Infrared sensor	340
Inclinometer	100
Micromotor	100
Microspectrometer	75
Emerging products	
Microdisplay	2,700
Fingerprint sensor	2,400
RF MEMS	500
Nebulizer	300
Needleless injector	300
Optical MEMS	290
Implantable micropump	360
Electronic nose	140
HVAC (automotive)	64

Source: Reproduced from NEXUS 2002 (Tables 2.1 and 2.2, p. 10).

One useful way of thinking about applications involving both micro and nano technologies is in terms of 'layers of packaging'. In many emerging applications, such as a diagnostic test or an advanced sensor, the critical active element (such as a specially treated surface or film) might be structured at the nano level. But this element will be set within a MEMS system providing analytical and other capabilities, and both will be encased in a 'macro' structure to facilitate easy operation. Many such applications will require and integrate both micro and nano capabilities, incorporated into a product or process at the macro scale.

Box 1. Some Key Nano Technologies

Nanotubes. Carbon nanotubes (layers of carbon atoms making up a tube) are among the key building blocks of nanotechnology. They have very high tensile strength, and high thermal electrical conductivity, and are semiconducting. They come in a wide variety of types, with different properties and applications, and will play a significant role in super-strong composites, electronics, sensors, super-strong textiles and filtration devices.
Fullerenes. Fullerenes are collections of carbon molecules, roughly spherical in shape. They have possible uses as lubricants and contrast agents, and in composite materials.
Nanoparticles: They can be made from a wide variety of materials, are already applied in some areas and are likely to have a wide variety of applications, from composite materials and surface coatings to UV creams and drug delivery systems.
Quantum dots and nanowires. These are tiny structures that confine electrons and can be made to emit light at different frequencies. If attached to particular molecules of interest, they offer possible applications in analysis and detection, in both medicine and electronics, even to the extent of detecting the presence of a single molecule of a substance.
Dendrimers. Dendrimers are complex designer molecules (polymers), and can be built up step by step to produce different configurations with different chemical properties. Given these capabilities, dendrimers are seen as having potential applications in drug design and delivery, and also in new composite materials.
Soft lithography. Various forms of this technology use a mold to imprint materials or to create new components at the nano level. It has important potential, and some actual applications, in medical systems and electronics.
Self-assembly. Self-assembling monolayers, where a substance forms a layer one molecule thick on a surface, offer many applications, as they allow the surface properties of materials to be readily modified. In the long run, designing nano systems that self-assemble into more complex structures is seen as having great potential in many applications.
Molecular nanotechnology. The goal of molecular nanotechnology is to make robotic machines or assemblers on a molecular basis, with the capability of constructing new materials an atom at a time, and of reproducing themselves. Such machines could have enormous ramifications, in terms of new materials, health, industrial processes and other areas. But such possibilities are very long term, are far from proven and are not the subject of significant commercial investment at this time.

Source: Harper and Hollister (2002) and CMP Cientifica (2002, 2003).

2.3 The Scale of Present and Future Applications

Many estimates are available, on different bases, about the likely future markets for products employing small scale technologies. But, as Cientifica (2003) has argued, the concept of a 'market for small scale technology' is close to meaningless, because small scale technologies will impact on virtually every industry and on many products, at different ways and at different times. The total value of the sales of products incorporating these technologies will be enormous, but this is not an estimate of the value of small scale technologies sales. The impact of small scale technologies will, over the next two decades, be massive, but it makes no sense to try to quantify this impact in a single market size figure.

However, to give some idea of the scale of the likely impact of small scale technologies, we have drawn on a variety of sources to assemble data on the scale of potential markets in the three opportunity areas of nanostructured materials, nanoelectronics and nanobiotechnology. Here we focus as far as possible on products that directly and centrally depend on small scale technologies, rather than products that use these technologies in one way or another. Consider first nanomaterials, which currently make up a substantial proportion of the total market for such products (roughly 25 to 30 per cent). Catalysts, the market for which is currently around US$30 billion, are expected to rise to US $100 billion by 2015. Nanoparticles and nanocomposites in manufacturing, currently around US$13 billion, are expected to rise to US$30 billion by 2006. One analysis indicates that nanomaterials could be a much larger proportion of the total spending on small scale technology products, say two thirds, by 2015.

In the area of nanoelectronics, coatings, particularly for hard magnetic disc drives, are currently around US$24 billion and this could grow substantially in the future. Much depends on the technology developed for sub-100 nanometre scale feature sizes for semiconductors. Current devices are approaching the limit for existing technologies, which will probably be reached around 2004 to 2006. The market for semiconductors, currently about US$140 billion, is anticipated to reach US$300 billion by 2006. Light and particle beams are being developed for production down to 10 nanometres but a paradigm shift to quantum computing could change markets dramatically. Nanotechnology is anticipated to contribute about US$300 billion to the electronics industry by 2010 to 2015.

In nanobiotechnology, about half of all pharmaceutical production (about US$180 billion) in 2010 to 2015 is expected to depend on nanotechnology e.g. microfluidics for drug assay and nanoparticles for targeted drug delivery. The market for medical devices and biomedical materials based on small scale technologies is expected to double in the next three years to about US$1 billion and thereafter to grow even more rapidly.

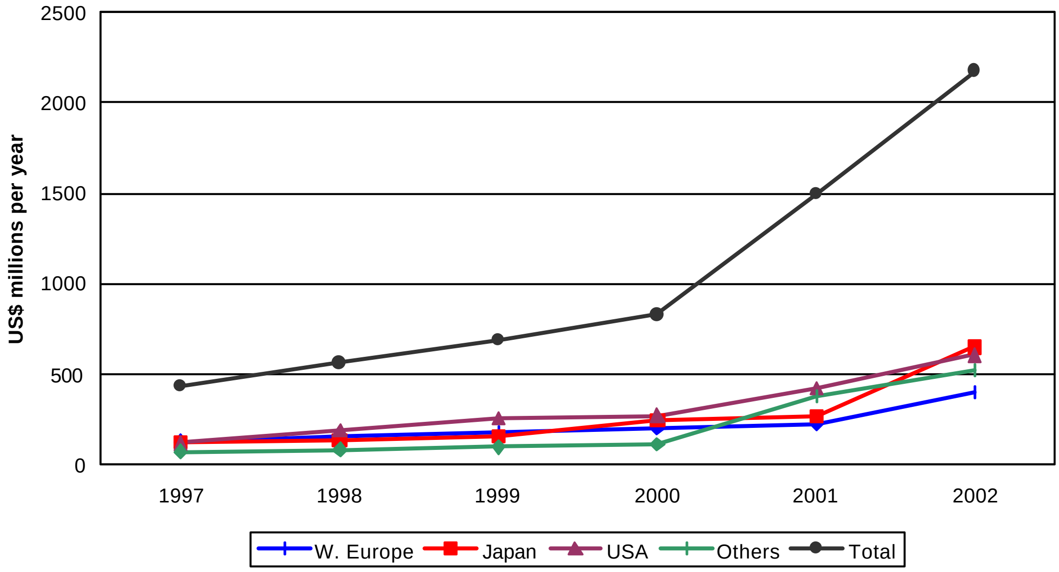
2.4 Government Responses

The long run potential of these technologies has led to major programs for government support for R&D in nanotechnology in recent years, especially in basic sciences. While there was activity in this area in the 1990s, the endorsement of a National Nanotechnology Initiative in the US in early 2000, covering a large number of departments and agencies and with a significant increase in funding on a continuing basis, sparked worldwide attention. At about the same time, Japan upgraded its already substantial activities in nanotechnology, and a number of other countries have put in place major programs. Japan, Korea and China have initiated national coordinating offices for nanotechnology.

One estimate of total government support for nanotechnology programs is that of Roco, from the US National Nanotechnology Initiative, shown in Figure 3 (Roco 2002). This estimate puts total support for these programs at US$2,174 million in 2002, an increase of 164% on that for 2000. Total support in 2002 was five times that in 1997. For most countries, signs of continued rapid growth in support for nanotechnology are evident, and the President Bush's 2004 Budget contains funding of US$847 million for 2004, an increase of 40% on the figure for 2002.

Nevertheless, these figures must be treated with caution, both because of the varying definitions of nanotechnology inherent in national figures and the embedding of nanotechnology R&D across many programs. For example, the European Commission has nominally allocated some ∈1.3 billion (US$1.42 billion) for a programme on nanotechnology as a thematic priority (1.1.3), in the Sixth Framework Programme over the period 2002 to 2006. A careful analysis by the European NanoBusiness Association (Roman 2002) concludes that nanotechnology is embedded in most of the thematic priorities and that a more realistic figure for nanotechnology is around ∈850 million (US$900 million) per annum, rather than the US$400 million included in the Figure 3 estimates.

Figure 3. Government Support for Nanotechnology Programs, NNI Estimates, 1996-2002



Source: Roco (2002).

Indeed, it is widely accepted that the NNI figures understate the level of government support for small scale technologies, and that in 2003 the total level of support is in excess of US3 billion (Cientifica 2003). Whatever the difficulties with the precise estimates, the overall picture is clear – there has been a dramatic upsurge in government support for nanotechnology programs since 2000, which is set to continue into 2004 and beyond.

A number of points about this upsurge of interest in nanotechnology on the part of governments are particularly noteworthy. First, government support has been heavily focused, especially in the US, on basic scientific research, on the assumption that further progress at the fundamental level is necessary if major applications are to become possible. But in the US, and also in countries such as Japan and Korea, such support for R&D takes place in the context of close linkages between R&D institutions and applications oriented firms. Second, again especially in the US, the focus is on nano rather than micro technologies, defined in the terms described above (nano technologies being those with feature size below 100 nanometres). Thus emphasis is not on more immediate applications of small scale technologies, but on supporting fundamental research in a context of close relationships between research institutions and companies.

Another important feature of investment on nanotechnology is that this is the first major technology in which Asian countries have a central position at an early stage. Thus nearly half of the US$2.2 million identified government support in 2002 (Figure 3) is in countries in East Asia (Japan, China, Korea, Taiwan and Singapore), with spending in Japan comparable to that in the US. China was the first country in the region to officially launch a national nanotechnology initiative in October 2001. The Chinese NNI has a budget of about US$240 million over five years. Korea is planning a ten-year nanotechnology development program with a total budget of 1.4 trillion won (about US$1.1 billion) over the ten-year period. Taiwan is planning its five-year science and technology programs, which include a national nanotechnology program with a total expected budget of US$450 million over five years. Singapore has also launched its national nanotechnology initiative, although the budget is yet to be made public. There have been indications and activities in the region showing increasing desire for enhancing regional collaboration and coordination in Asia Pacific nanotechnology development (see, for example, Asia Technology Information Program Reports, www.atip.org/NANO).

2.5 Social and Ethical Issues

The growth of modern science, and the power that it has provided to the human community to control the natural world for human use, has generated deep-seated social and ethical dilemmas. Increased power over the material world has given us many products that enhance human life, but has also led to global warming and nuclear weapons. Medical research has contributed greatly, both through new drugs and medical procedures and through preventative programs, to a longer and healthier span of life for many people, but has also raised deep ethical and social issues.

In the longer term, nanotechnology is likely to involve much more fundamental knowledge of matter, and of the material foundation of human life, than has been available to date, together with a commensurate power to intervene in physical and human processes. As Roco and Bainbridge (2001) point out, the envisioned breakthroughs include ‘orders of magnitude increases in computer efficiency, human organ restoration using engineered tissue, ‘designer’ materials created directly from atoms and molecules, as well as emergence of entirely new phenomena in chemistry and physics’ (p. 1). Given the increased technological power that it is likely to deliver, nanotechnology will raise to a new level the social and ethical dilemmas emerging from modern science.

In general terms, the main issues are familiar if not at all easy to resolve. They include:

- the environmental and human health issues raised by the increasing use of nanoparticles and the creation of new forms of matter;
- the privacy and security issues arising from vastly increased computing power and from a new wave of defence technologies;

- issues about the nature, identity and preservation of human life arising from new generations of medical technologies based on individual genetic structures;
- questions about the human/machine interface, with increasing capability to incorporate artificial components into human beings and to build 'intelligent' machines; and
- the equity issues, across both individuals and countries, about access to the benefits of small scale technologies.

Fundamental as these issues are, it is necessary to keep the development and application of small scale technologies in perspective. Micro technologies, many of which raise less dramatic issues, are likely to remain the main game for some time to come, although increasingly wedded to nano scale probes, instruments or components. Many of the more revolutionary nano developments – such as complex, self replicating robotics machines with extensive functionality – are several decades off, and are yet to be scientifically proven.

Nevertheless, it is important that, as the scientific and technical community pursues the development of small scale technologies, the broader community becomes aware of the issues they raise and develops the capability to think seriously about these issues. As Mnyusiwalla, Daar and Singer (2003) point out, this is not just a matter of increased funding for social and ethical research in these areas. Indeed, they note that in the US less than half of the funds allocated in the National Nanotechnology Initiative for the study of societal implications have been spent, in part because of the lack of meritorious research proposals. A broader process of awareness raising and capability strengthening is necessary, including the development of substantial inter-disciplinary research platforms.

2.6 Education and Training

The discussion of the previous section raises issues of community awareness of nanotechnology and the need for provision of education programs reaching into the public arena. An important starting point is the role of the media in reaching the general populace through newspapers, television and radio. Information needs to be provided to ensure that there is a balanced consideration of all the various issues involved in the development and use of small scale technologies. The issue has already attracted the attention of groups overseas such as Greenpeace and a Canadian group called ETC (Erosion, Technology and Concentration). ETC early this year issued a manifesto calling for a moratorium on nanoparticle research (particularly aimed at nanobiotechnology) until the issues of the use of nanoparticles have been considered by all the relevant UN bodies.

An important group is the young people at school, where there is continuing reluctance of able students to pursue careers in science and technology. The introduction of technology options in State curricula offers an opportunity to showcase nanotechnology. An interesting experiment is the Nanotechnology Centre grants awarded by the National Science Foundation to US universities which specifically task the universities to link to local high schools and to develop learning modules and projects which encourage students to use advanced equipment in the universities.

A looming problem is the education and training of a new generation of researchers and skilled workers with the interdisciplinary perspectives necessary for rapid progress in small technologies. A recent estimate quoted by Roco (2001) of the people needed for nanotechnology in 2010-2015 is 800-900,000 in the US, 500-600,000 in Japan, 300-400,000 in Europe, and 100-200,000 in the Asia-Pacific region excluding Japan. These numbers can only be taken as broadly indicative of emerging demand, but countries are reacting to these anticipated needs by encouraging the development of new undergraduate courses and expanded post-graduate programs. In this area Australia has taken a leading role with the establishment of the first undergraduate course in nanotechnology in the world at Flinders University over three years ago. Several other courses will be commencing in the near future, so that up to 100 graduates a year could be produced within five years. There needs to be networking within Australia and with overseas institutions in the area of nanotechnology undergraduate education.

The role of TAFE institutions is vital in building up skills in the workforce in nanotechnology to enable research to be translated into commercialization; some of these TAFE institutions are linked to universities and can provide routes for interchange in learning modules and experiments. Given the potential for widespread change in industry as a result of developments in small technologies a critical component of an education system for the future is the introduction of the concepts of small technologies into management courses with appropriate case studies to alert them to the changing technology environment. These and other issues concerning the crucial role of education and training are taken up further in Section 4.5 of this report.

2.7 Small Scale Technologies in Australia

2.7.1 The National Scene

One leading international observer of nanotechnology has assessed the situation in Australia in unflattering terms:

> In the past there has been little effort to understand the potential of nanotechnology, and most decision makers are uncertain about the value of investing funds in nanotechnology R&D. … this has led to a climate of very little government support for nanotechnology and a distinct disinterest on the part of the commercial sector. One reason for this is the country's dependence on primary production in the form of minerals and agricultural products, where the applications of nanotechnology have not been obvious. (Cientifica 2003, p. 52)

While there is, in our view, some truth in this assessment, it overstates the position because of the diversity of ways in which small scale technology is supported and the lack of any coordinating national vision. At the Australian Government level there is no strategy for nanotechnology or for small scale technologies, such as have been developed in many countries and are referred to above. There is, however, a comprehensive set of National

Priorities have been developed after extensive consultation in late 2002. The National Research Priorities are:

- an environmentally sustainable Australia;
- promoting and maintaining good health;
- frontier technologies for building and transforming Australian industries; and
- safeguarding Australia.

Each has a number of associated priority goals and nanotechnology is specifically mentioned in three of the four under Frontier Technologies, namely:

- Breakthrough science - nanoassembly and quantum computing
- Frontier technologies - nanotechnology
- Advanced materials - biomaterials, smart materials and composites.

However, examination of all the priority goals suggests that nanotechnology could play a significant role in many areas, e.g. through improved sensor technologies in environmental applications, through improved diagnosis and drug delivery systems and point-of-care treatment in health applications and in sensor technologies for bio-terrorism.

Given identification of these priorities, there is clearly a need to ensure that Victorian activities and strategies complement and build upon the national thrusts, since Australian Government funding will be directed to these in the future. In the recent ARC round, for example, some 50 nanotechnology-related research projects received funding of A$15 million over three years to 2005.

While precise figures are not available, it seems that Australia spent about A$50 million on nanotechnology R&D in 2002 and that this may approximately double in 2003. This is comparable to spending levels at the government level in Korea and Taiwan. However, unlike these two countries, there is currently limited interest in commercializing nanotechnology in Australia. This may in part reflect the limited capability in the microelectronics industry in Australia, with major Australian areas such as agri-food and minerals resources are relatively low in research intensity compared to the electronics industry.

In the scoping study by Ernst and Young in 2002, a SWOT analysis was made of technology drivers and constraints in regard to Australia's position in nanotechnology. The results are summarised in Table 2.

Australia's strengths are likely to continue but the present industrial structure will be difficult to change. Control of many companies is in the hands of foreign firms, which tend to use technology developed elsewhere. The Australian market is relatively small and high tech companies can only expand through alliances with overseas firms. The case of Advanced NanoTechnologies is a good example. Formed as a spin-off company of the University of Western Australia to exploit novel reactive ball milling of nanopowders, it has only been able to expand through a joint venture with Samsung Corning of South Korea. A major plant is being set up in Korea to service the large electronics market in that region.

Table 2. Analysis of Australia's Capabilities and Relative Deficiencies in Nanotechnology

STRENGTHS	WEAKNESSES
General cost advantage over many nations	Often less competitive than regional neighbours in high technology
Stable open-market economy	Taxes a disincentive for investment
Good supply of trained people	Limited talent pool with entrepreneurial approach
Rapid take-up of high tech products	Limited manufacturing base for high tech products
Broad Federal and State support for small technologies	Low expenditures by industries which could benefit
Strong basic research in small technologies	Expenditures relatively low in global terms
Excellent communication infrastructure	Limited use for networking among interested groups

Source: Adapted from Ernst and Young (2002).

The strategies of the major Australian Government research organizations are important since their activities cover several States and their priorities may not always coincide with those of the Victorian Government. Thus in CSIRO 17 Divisions across Australia have indicated that they have some activity in nanotechnology and CSIRO is currently making a detailed audit. In Victoria CSIRO has strong representation in nanotechnology through Divisions in the Clayton complex and others in Preston, Highett, Parkville and Geelong. It is a major participant in NanoVic with some of these activities.

Similar considerations apply to DSTO, which has a strong presence at Fisherman's Bend and at Maribyrnong but also has major facilities in South Australia in the electronics area. While DSTO is not a core participant in NanoVic there is a strong interest in using the equipment of the participants and also MiniFAB for device fabrication.

A national resource is the Nanostructural Analysis Network Organisation established as a Major National Research Facility with core funding from the Australian Department of Education, Science and Training. The organization is headquartered at the University of Sydney and draws together specialized facilities for nanostructural analysis in universities in New South Wales, Victoria and Queensland.

2.7.2 The State Scene

While a major component of funding for nanotechnology is provided by the Australian Government, the State governments are also funding activities within their States. The degree of support reflects the social, economic and industrial structures together with the aspirations of each State. The two States that give the strongest support are Queensland and Victoria- a similar situation to that which prevails in biotechnology. New South Wales has more limited activity in the area.

Queensland in 2001/2002 earmarked A$ 63 million for stimulating innovation, particularly in advanced technology areas. Of the six projects that were funded, two were on nanotechnology. The University of Queensland, with the support of the State Government, has established the A$50 million Australian Institute of Bioengineering and Nanotechnology. This is complemented by strong university groups in these areas, notably the Nanomaterials Centre at the University of Queensland. CSIRO has interests in applications of nanotechnology through its strong grouping of biotechnology, primary industry and resource Divisions in Queensland.

The University of New South Wales has an ARC Special Research Centre for Quantum Computer Technology which expanded in 2000 from a Semiconductor Nanofabrication Facility with an A$9 million from ARC plus a matching amount from four Australian Government departments over three years. This Centre has links to universities in Queensland and the University of Melbourne. Further the University of Technology Sydney has a developing Institute for Nanoscale Technology.

Victoria has centres of expertise in nanotechnology in its universities and in CSIRO divisions. The strong medical and biotechnology research and commercialization activities provide the opportunity for significant interaction in the nanobiotechnology area. The Victorian Government has awarded A$12 million over three years from its Infrastructure Development Program to support the setting-up of NanoVic, which draws together most of the major R&D groups of universities and of CSIRO in Victoria in a unified approach. The participants will provide cash and in-kind support approaching A$30 million over three years. Through a company structure, NanoVic will support four fundamental platforms – design and processing at the nanoscale, characterization of the performance of nanoscale systems, nanoscale structural characteristics, and modelling of nanosystems. These will be focused into three research programs - nanofabrication and characterization, chemical and biomolecular nanotechnology, and nanostructured materials. An aim is to create an Australian Centre for Molecular Nanotechnology and thus exploit opportunities in the health and pharmaceutical sector, and in the advanced manufacturing sector in Victoria.

A further advantage for Victoria is the construction of the Australian Synchrotron to be completed by early 2007. The synchrotron will be a powerful facility for undertaking small scale biological and materials analysis and for small scale manufacture. The basic infrastructure is being largely financed by the Victorian Government and groups will finance their own beam lines. An initial complement of nine is planned with capacity for up to thirty two beam lines. While the majority of these will be for research, the opportunity exists to stimulate industry participation to provide advanced problem-solving capability such as exists overseas and to encourage spin-off high tech companies through an incubator program.

The Cooperative Research Centre for Microtechnology is headquartered in Victoria at Swinburne University with links to institutions and industries in Queensland, Western Australia and New South Wales. It has strong research programs with international links in fabrication technology, microdevice packaging and systems integration, safety and health microsystems, and microfluidics. Furthermore, it has nearly 50 post-graduate students working in its programs. It is a significant resource for Victoria in small scale technologies.

Finally another initiative in Victoria is the MiniFAB facility, which houses micro-and nano-fabricating equipment for producing devices such as sensors, diagnostics, micro-instruments and tooling. This has been set up by the Industrial Research Institute at Swinburne University with private sector support. With appropriate upgrading this will provide a unique prototyping facility in Australia, which already is being linked to a business incubator. MiniFAB has announced that it will invest in a beamline at the Australian Synchrotron for product fabrication.

3. Industry Implications and Victorian Capabilities

This section of the report reviews, for a range of industries important to the Victorian economy, the major commercial applications of small scale technologies that can be foreseen with reasonable assurance, and summarise some of the implications for these industries. For each industry an assessment is made of which part of the industry is most likely to benefit from the utilisation of small scale technologies. In addition, the extent of knowledge about and adoption of these technologies is described where this is known as is the main scientific and technological capabilities in Victoria in these sectors.

3.1 Human Health

Health can be looked at from two perspectives: as the sector of the economy using knowledge and technologies, and the devices and products in which they are embodied, to provide services to individuals, and as the industry creating, marketing and distributing those knowledge intensive products. While realizing the close links between these two perspectives, we use this dichotomy to discuss the impact of small scale technologies on health.

3.1.1 Health Services

It is widely believed that the convergence of low cost communications and information technology, and the development of nanotechnology based disease detection devices and other biosensors, has the potential to revolutionise the delivery of health services. In particular these technologies have the capacity to enable customised and specialised health care for both diagnosis and treatment to be delivered outside large centralised health institutions. This could involve individual delivery of medical services at the local clinic or even at home through communications networks and small scale devices.

One of the enabling factors in this possible revolution is the likelihood of being able to provide highly personalised treatment regimes based on the characteristics of each individual patient's specific genome. The mapping of the human genome has opened up the possibility of designing programs of treatment specifically in response to identified individual genetic disease dispositions. In particular it has introduced the possibility of personalised drugs to suit each patient's genetic makeup. As the CEO of one leading biotech firm has been quoted as saying:

> One day, everyone will have their own genomes mapped out and stored in memory chips, and doctors will look at the information in those chips, and prescribe accordingly.[1]

Personalised medicine could, for example, have far reaching implications for the pharmaceutical industry. The industry is dominated by a small number of global companies each with a high level of dependency on selling blockbuster drugs – those with sales in excess of US$1 billion. In 2001 almost half (45.6%) of the total sales of the top 10

[1] Mark Levin, CEO, Millenium Pharmaceuticals.

pharmaceutical companies were due to sales of only 35 drugs, each with sales of over US$1 billion. Personalised medicine could change that business model radically, by requiring the distribution of small quantities of a much larger range of personalised drugs. In these circumstances pharmaceutical companies could seek to have a direct relationship with the patient, for example via the Internet or through the patient's virtual physician.

The impact of information and communications technologies – with low cost comprehensive data bases of patient records, remote delivery of medical services, so called telemedicine and increasing use of the Web by consumers for health information - has been with us for some time and its implications have been discussed in the literature. Hospitals and health management organisations have grappled with the challenges of implementing these databases. The first US patent for a computerised system for the delivery of patient specific drug information was awarded to Multum Information Systems in 1999. The system has the capacity to generate dosage recommendations based on specific patient medical condition data (Health Management Technology 1999) Increasingly physicians have been persuaded to make their prescriptions legible by using pocket PC's that record and display patient drug interactions, run allergy and other checks at the point of care and can transmit the scrip directly to the preferred pharmacy.

Delivery of medical services to remote areas has been much improved at a lower cost by telemedicine and even remote surgery is now possible. The design of certain therapeutic and diagnostic devices has been facilitated the shift of point of care to the domestic environment. For instance, a Chicago based company InterCure introduced a prescription medical device that helps monitor and lower blood pressure in the home.

A range of microtechnology-based devices have been developed which address particular medical conditions. The earliest of these were disposable blood pressure devices that cost about US$10. More recently micropumps that can deliver insulin drugs in dosage sizes measured in nanolitres have been developed, and implantable pace makers that control irregular heart rates and implantable hearing aids are available. These devices have some distance to go before they offer the comprehensive diagnostic care being envisaged in some models. Not only do they need to cover a broader range of medical conditions but the integration between the devices and the available communication and information systems is necessary to transform prospective prototypes into fully fledged products.

Nanotechnology offers the potential for a plethora of relatively non-intrusive but powerful and comprehensive diagnostic devices that could provide the basis for increased domestic applications. For example, the Australian company Ambri is developing a diagnostic device that will undertake blood analysis in an emergency ward context that takes minutes rather than 12-24 hours through the pathology lab. Its impact will initially be in the hospital ward but it may be a precursor to the types of devices necessary to provide comprehensive diagnostic services in the domestic environment.

Notwithstanding the technical challenges, there is a convergence of technological trends, of which nanotechnology is one, that could radically alter the delivery of health services. Domestic delivery of health care seems likely to be one component of high quality health care to be demanded by an aging population seeking longer but still comfortable lives.

3.1.2 Health Products

While much biomedical research and product development draws upon molecular biology and biotechnology, which work with nanoscale biological molecules, international applications of nanotechnology in the life sciences area have focussed on three main areas (Malsch 2002; Saxl 2002).

Diagnostic devices. This includes biosensors and 'lab-on-a-chip' devices that test for particular substances or drugs, analyse blood or test for the presence of other chemicals. They rely on advances in nanotechnology such as the ability to attach very thin layers of biological material to various types of sensor substrates, or control the flow of miniscule amounts of fluids through nano sized channels to provide almost instantaneous analysis. The applications typically require sophisticated monitoring and detection devices to receive and process the information from the sensors.

CSIRO (2003) has defined three target markets for diagnostics. The first is in intensive care requiring continuous monitoring of drugs and analytes. The second is pathology labs demanding high through put screening and the third is point of care where rapid diagnosis is required. While in its early stages the application of biosensor technology could be quite revolutionary in changing the delivery of health services. As noted earlier, automated diagnosis by biosensors could shift point of care from institutionalised to decentralised locations for more personalised delivery.

Drug discovery and delivery. Drug discovery productivity has been massively improved by high through put screening of potential drug candidates. Nano technology develops this further in a number of ways. Uniform nano sized particles can be used to provide more sophisticated optical detection of reactions between drugs and their targets. The ability to detect molecules attached to uniform nano sized particles can significantly improve the productivity of high through put screening technologies. The engineering of proteins by the manipulation of the constituent amino acids can optimise the function of drugs, significantly improving their efficacy by many times their original formulation.

A large amount of research and development is being done on improved methods of delivering drugs in the appropriate amounts to the correct sites within the body. Dendrimers and other scaffolds such as liposomes are being used to ensure that drugs are able to navigate the digestive tract and immune system and to reach their targets. These small scale technologies will enable lesser amounts of toxic drugs to be used, and will make it easier to deliver multiple drugs to the one target.

Prostheses, implants and other applications of biomaterials. The ability to gain greater control of material properties using nanotechnology means that prostheses and implants can be designed with more specific functions and with better performance than has been possible. The properties of naturally occurring biomaterials in bone, tooth and other biological materials have been shown to depend on the nanoscale structure of their constituent materials. There is potential therefore to both learn from this in designing materials for other uses and to use this knowledge in the design of new biomaterials.

While this has the potential to improve current applications such as catheters, coronary stents, pacemakers, insulin delivery systems, cochlear implants and the cultivation of replacement skin and other body parts, further utilisation could see the development of retinal implants to restore sight and the ability to replace or restore most body systems.

3.1.3 Victorian Capabilities

An analysis by CSES of worldwide biotech and pharmaceutical alliances involving nanotechnology shows that of those formed since 2000, 58% are concerned with drug delivery and design. Of the remainder most are concerned determination of protein structures and with various applications using nanoparticles or in the manufacture of biochips. Most applications falls within the wider 'drug discovery and delivery' category, while nano particle applications include the use of very small, magnetised particles in imaging, improving the productivity of assays, and in the development of biostructures in tissue engineering products.

While many applications are being suggested, the study of the properties of nano sized materials and particles is at such an early stage that defining its potential applications remains to some extent a matter of conjecture. For instance, nanotechnology could have application to most areas of the drug production value chain – from discovery and development to manufacturing and delivery.

Victorian capabilities mirror these international trends. The most prominent commercial application of nanotechnology is the work on drug delivery and design by Starpharma Pooled Development Fund (PDF), a listed PDF, which is developing drugs using a dendrimer platform, a nano scale structure, to which drugs are 'attached'. Its most advanced application is due to begin human trials this year. Starpharma has a dominant position in world patents in dendrimers and is seeking alliances with leading global pharmaceutical firms. Some indication of its potential commercial value is the US$545m alliance formed by Glaxo with a private biotech developing similar drug delivery and design technologies (ReCap 2003).

Eiffel Technologies is also pursuing nano based drug delivery technologies. The company uses super critical fluids (SCFs) to improve the delivery of existing drugs in aerosol form. For asthma sufferers the smaller particle size means better absorption of inhaled drugs. The company is also working on inhaled delivery of otherwise injectable drugs. Eiffel has formed alliances with overseas partners including Sheffield Pharmaceuticals and Batelle Pulmonary Therapeutics to use its SCF technology to improve the effectiveness of reformulated drugs. Interestingly Batelle, which is itself a private, unlisted pharmaceutical company has formed an alliance with GlaxoSmithKline to promote its own Mystic drug delivery system.

There are a number of research units, some within the CRC on Microtechnology, others within NanoVic, including RMIT, Swinburne and the Parkville campus of the CSIRO, focussing on various applications of nanotechnology to biosensors and similar devices. As with such applications in other parts of the world, their commercial development appears to be some distance away. In addition to the technical challenges involved in the production of sensors, much is required in order to transform biosensor components into fully functioning products.

Led by Prof Peter Hudson, at its Parkville campus, CSIRO has an active research program focussing on quantitative assays of proteins and nucleic acids based on biosensors. This research is likely to contribute to applications that include high through put clinical analysis. Biochips are to be developed using various nanotechnologies such as artificial membrane bilayer assemblies.

At RMIT, Professor David Mainwaring is leading a team working on the design of biosensors and similar diagnostic devices. He receives biological material from CSIRO, other parts of RMIT and Latrobe University which he attaches to appropriate substrate. Professor Dan Nicolau at Swinburne is also working on biosensors substantially funded by the US government agency, DRPA. His work on bio information systems is at this stage still basic research, with possible commercial application some way off.

One local application of nano particles, which has had some commercial application, is Prof Paul Mulvaney's work at the University of Melbourne on quantum dots, which, in collaboration with the US Quantum Dot Corporation, is being used as an input into a new drug screening technology.

The Centre for Green Chemistry at Monash University has developed new biocatalysts based on molecular recognition and molecularly imprinted polymers to achieve major efficiency gains in the production of pharmaceuticals. These nano scale techniques have the potential for wide application in industrial processes.

These research initiatives should give Victoria good capabilities in biosensors and other diagnostic products for which there is considerable market potential. It is intended that NanoVic will have a commercialisation capability. However at this stage, the most likely vehicles to promote the commercial application of this work is the CRC for Microtechnology and the CRC for Diagnostics.

Both CRCs have industry partners relevant to the commercialisation of diagnostics and biosensors. Motorola, a participant in the Victorian based CRC for Microtechnology has an interest in developing the associated detection and information management systems for biosensors. The Queensland focussed CRC for Diagnostics, which would be the likely vehicle for commercialising diagnostics originating from Peter Hudson's group at CSIRO, has a number of potential industry partners including PanBio.

3.1.4 Demonstration Project

One of the oft-sited complaints of the nano research community is that there would be more use made of nanotechnology if industry understood its benefits, e.g. opening new markets or reducing costs. The application of nanotechnology in biosensors and diagnostics is one area where a demonstration project could be extremely valuable. Diagnostics and sensors have the potential to be a highly disruptive technology. For instance they could transform the delivery of health services. Placing small inexpensive diagnostic devices in the hands of GPs and paramedics that undertake blood or other tests for particular pathogens or diseases could radically shift the point of service from hospitals to GPs surgeries or even to the home for self administered drug treatment regimes.

Indeed these possible changes in favour of decentralised point of care are consistent with the potential trends towards the development of personalised medicine arising from the decoding of the human genome. This work offers the prospect of drugs designed to match personal genetic defects, or susceptibility to particular diseases, supported by comprehensive personalised information systems. In a futuristic article, PriceWaterhouseCoopers envisioned a world in which a personalised 'health check' device provided a daily disease diagnosis and a computer linked to a comprehensive personalised health information system prescribed appropriate doses of individualised medicines (1999).

For this vision to be realised however requires the development of a series of completely different business models for the delivery of health services. This in turn requires a much better understanding of the capability of the technology to deliver useful products, the cost of manufacturing such products and likely demand. Prototype products need to be designed and used in a controlled environment where their impact can be observed.

To demonstrate the possible effectiveness of these devices, how they might be used, and how they their use might be integrated to deliver health care, a demonstration 'clinic' could be established where the devices could be displayed, tested or demonstrated. Clearly there would be restrictions on the use of untested devices on humans, but equally such a demonstration site could help stimulate the imagination of industry and help bridge the 'commercialisation gap'. Amongst the various nanotechnology players in Victoria, MiniFAB would be best placed to establish such a project. It has fabrication facilities that could be harnessed to manufacture prototypes and has a significant incentive to interest companies in the benefits of nanotechnology.

In designing such a demonstration project, it will be necessary to involve a range of health professionals so that whatever system is developed meets their needs and hence facilitates its uptake.

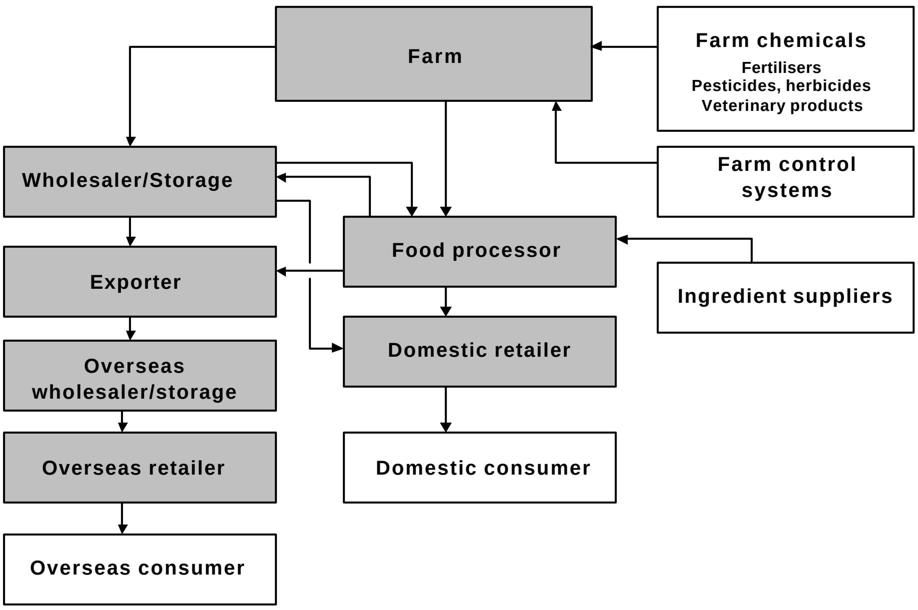
3.2 Food and Agriculture

Victoria's agricultural and food processing industries are major contributors to the State's economy supplying both the Australian and overseas markets. Agriculture employs 90,000 people while food processing has a workforce of 47,000. Food processing is the largest sector within Victorian manufacturing and is responsible for about 34% of manufactured exports. These sectors are also important markets for suppliers of agricultural chemicals and fertilisers, veterinary products, farm equipment suppliers and a large part of the packaging industry.

The food value chain stretches from the farm to the consumer and is illustrated in Figure 4. Farmers typically produce fresh produce that is sold either directly to food processors or to storage with a wholesaler or other intermediary. The food processor then either supplies the retailer directly or through a wholesaler. For overseas sale there are usually more links in the supply chain to the final customer, involving export agents, overseas wholesalers and retailers. Transport will usually be needed to move the product from one link to the next in the supply chain and there is likely to be a need for further storage on site.

A key feature of Victoria's strategy for the development of the food industry is the 'clean, green' image associated with the State's food products. This means that it is important to demonstrate that food products are free from residual chemicals used in growing, processing and storing food, and from pathogens that may be introduced along the supply chain. In addition it is important, especially for fresh or lightly processed food, that deterioration through the supply chain be minimised to ensure maximum shelf life.

Figure 4. Food Value Chain



Small scale technologies have the potential to contribute to achieving these goals and to giving farmers and food processors greater control over product characteristics, as well as helping to achieve higher levels of productivity. In particular, cheap sensors can play an important role in systems that control production and distribution to maintain desired product characteristics, such as freshness and freedom from contamination.

3.2.1 Food Production

Growing **plants** with the desired characteristics relies on the right combination of a number of different factors. They usually need the application of pesticides and herbicides to control insects and weeds respectively, and fertilisers and other nutrients to promote growth. The cost to the farmer of using these chemicals can be minimised if the correct amount can be applied at the optimum time.

Heavy rain and over-irrigation can result in traditional chemicals being dissolved and removed from the soil into groundwater or streams. Not only is this wasteful economically but it has serious environmental repercussions in its impact on the ecology of waterways and the quality of drinking water derived from these sources.

CSIRO and other research organisations are working on methods to encapsulate agricultural chemicals in nanostructures, in such a way that their release in the field can be better controlled. This means that less of the chemical is needed to achieve optimum results and that the release of these chemicals to the environment can be minimised. In addition, if the particle size of agricultural chemicals can be controlled at the nano scale, their efficacy can be enhanced, with more of the active ingredient being available for its intended application.

Raising livestock requires pasture and hence the same range of chemicals. In addition veterinary pharmaceuticals and other chemicals are need to control pests, disease and parasites. Nanotechnology can be used to produce cheap, disposable diagnostic tests to detect the presence of these conditions and enable more targeted intervention to control them.

In a good year, Australian farmers spend about $3.5 billion per year on fertiliser, agricultural chemicals and veterinary supplies and services to support sales of around $25 billion. If nanotechnology could improve the usage of these farm inputs by 10% this would mean savings of $350 million in farm costs. In addition if nanotechnology could deliver a 1% expansion of sales through higher productivity and improved quality of farm produce this would provide a benefit of $250 million. In total therefore nanotechnology could contribute $600 million to gross profits.

The largest Australian supplier of crop protection chemicals is Nufarm, which is based in Victoria. The company is actively engaged in research to develop mechanisms at the nano scale to deliver their products more efficiently and to make them more efficacious. Their research program is partly motivated by the desire to provide their customers with ways of using smaller applications of chemicals while still ensuring the same or better levels of efficacy. The approach is to control particle characteristics and to ensure controlled release of chemicals while minimising environmental impact.

A similar approach could be adopted for improving the efficacy of veterinary pharmaceuticals. In the same way as is being proposed for human drugs, nanotechnology could be used to design and manufacture scaffolds such as liposomes and dendrimers and similar compounds, to ensure better animal drug delivery with controlled release of active ingredients at targeted sites. Improving the delivery and efficacy of animal drugs would lead to cost savings and healthier animals.

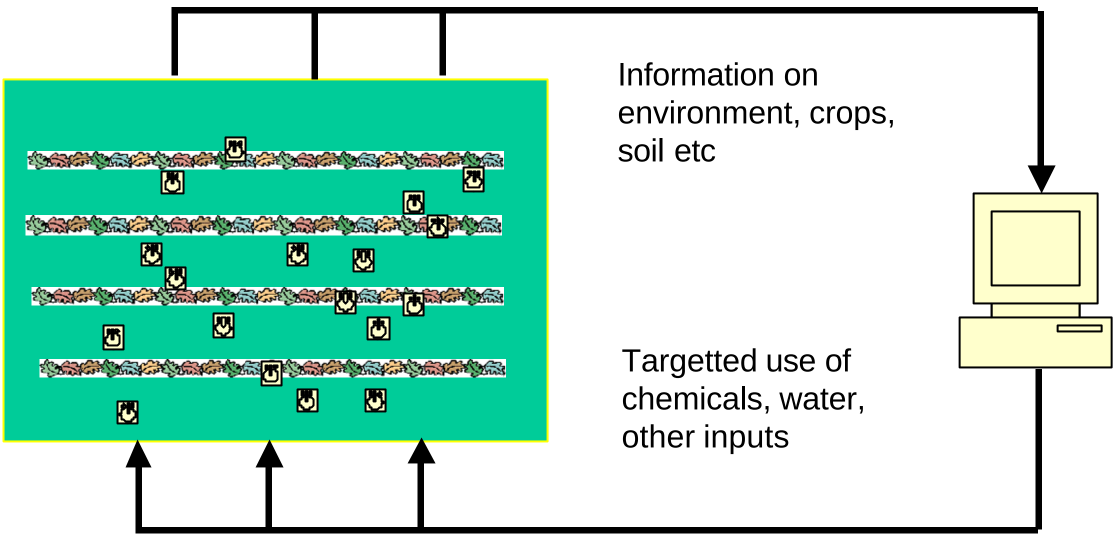
While nanotechnology has the potential to contribute to better types of agricultural inputs such as agricultural chemicals, it can also be deployed in farm control systems. If farmers have better real time data on what is happening on their farms they can plan their interventions more effectively not only in the application of chemicals but in the use of water, the timing of planting and harvesting.

Nanotechnology has the potential to enable cheap, disposable sensors to be used on farms to provide data on variables such as air temperature and humidity, air speed and direction, soil composition, amount and type of nutrients, presence of plant pathogens, amount of pollen, and composition of crops at various stages of development.

Information from large numbers of sensors spread across fields would enable the farmer to allow for variations in conditions and apply interventions, such as irrigation water, in a targeted, more selective manner. The use of a system of sensors like this would contribute to improved crop and animal yields, higher and more consistent quality for produce and reduced costs, as fewer inputs are used. As farm chemicals would be used selectively and only as needed, it would also reduce the environmental burden of these chemicals.

The Cooperative Research Centre for Microtechnology, based at Swinburne University, has been developing a project in the application of cheap, disposable environmental sensors with one of its commercial partners, Motorola. One application for these sensors could be within vineyards (Figure 5), where they would be mounted within a stake that could be driven into the ground at various locations to report on the kinds of environmental and other characteristics outlined above.

Figure 5. Sensor Control System for a Vineyard



Other uses for sensors in agriculture include detection of pathogens and parasites and other diseases in animals and monitoring waste from intensive animal production such as piggeries The CRC for Microtechnology has research projects in both controlled release of vaccines in food animals and microsensors for pathogen detection in the intensive animal production industry.

3.2.2 Food Processing

Victoria has a large and diverse food processing industry. It is particularly strong in diary products, but has a substantial presence in meat and seafood products, fruit and vegetable processing, cereals based manufacturing, pet foods, and confectionery. It has major facilities in malt and beer making and its wine industry has shown strong and sustained growth over recent times.

Much of the industry has a strong export orientation and faces the constant challenge of developing new products and adapting existing products to meet the needs of consumers in a variety of different countries.

A key competitive advantage of Victorian food products is the perception among consumers that they are produced within a clean and healthy environment. It is important therefore that products are free from chemical and pathogen contamination and that they are either fresh or in good condition when presented to consumers. This creates significant logistical challenges for the distribution chain in terms of timely delivery, and monitoring and control of the product and environmental conditions while in storage and transit. This in turn requires significant innovation in packaging.

Food processing often uses processes that operate at the nano scale. Making food products involves combining raw materials from a variety of sources with other ingredients, such as flavours, preservatives and extenders, under different atmospheric and temperature conditions. In many food products, the materials that go into them are either nanoparticles or they combine to form particles and structures at the nano scale, for instance through the interaction of carbohydrates and proteins.

Greater control of particle size and characteristics will enable food producers to design and manufacture products with improved flavour, colour and nutrient content. New techniques for encapsulating food ingredients at the micro and nano scale will mean that oils in foods such as sauces, mayonnaises, margarines and other products can be more readily stabilised. This will ensure longer shelf life and prevent separation of ingredients. It should also reduce the need for antioxidants, stabilisers and emulsifiers to be added to food.

This encapsulation technology is also important in the development of so-called nutriceuticals, ie. foods that contains ingredients that provide health benefits in a fashion similar to traditional pharmaceuticals. Encapsulation enables these desirable ingredients to be delivered to the appropriate part of the digestive system and be released as required.

Again as a parallel to human drug delivery, liposomes and dendrimers can act as suitable transport mechanisms for the active ingredients within nutriceuticals.

Sensors have a role to play in food production in the detection of volatiles and odours in food processes and in automated testing of products and ingredients. Sensors can act as ‘electronic noses’ and ‘electronic tongues’ simulating human ability to detect smells and tastes. These sensors can be used in testing during production and in laboratory testing and also potentially can be incorporated in packaging to detect chemicals given off at various stages as a product ages.

Some parts of the food industry such as brewing and dairy products utilise fermentation and similar techniques in their production processes. Separation and filtration are important requirements within these processes and nanotechnology can be used develop membranes and other filters that can screen out or pass through certain molecules based on their shape and size. This gives better control of particles involved in flavour and other food characteristics as well as improves ability to remove toxins and other undesirable compounds.

Food Sciences Australia, which is a joint initiative of CSIRO and Victorian Government research institutes, has a number of research programs aimed at utilising spray technology to control particle properties in processes such as spray drying, coating and encapsulation.

The CRC for Biopolymers, involving the University of Melbourne, CSIRO and ingredients company Albright & Wilson, is working on controlling the characteristics of one type of food ingredient, namely plant biopolymers or gums which are used extensively in processed foods such as jam, jellies, soft drinks, cake mixes, sauces, dressings, ice creams, yoghurts and processed meats. They do this by thickening or gelling the liquid, or by emulsifying components which would not normally disperse in liquid.

Techniques such as spray drying are already utilised in the food industry and as noted above, much of food research is aimed at understanding and manipulating the materials going into food production at the nanoscale.

This means that the technical and knowledge barriers to greater takeup of nanotechnology in the food industry may not be as great as in other industries, and there is considerable potential for nanotechnology to have an impact in much of the industry. However, the level of R&D undertaken in the food industry is low compared to other parts of the manufacturing sector, so the knowledge of new developments in nanotechnology and their potential for improving products and processes within the food industry is still underdeveloped.

Part of a strategy to encourage greater interest in and adoption of nanotechnology in the food industry may therefore just involve a recognition that nanotechnology is simply the logical extension of science and technology that is already is well known and accepted.

A good example of how nanotechnology is being promoted within the food industry is Kraft Foods in the USA, which established its own nanotechnology laboratory in 1999, as well as a ‘NanoteK’ consortium which includes 15 universities and research laboratories such as Harvard University and the Argonne and Los Alamos Laboratories. Examples of the research being undertaken by this consortium include:

- encapsulation of ingredients which are smart enough to recognise a person's profile, such as allergies of food deficiencies, and release the appropriate ingredient to meet this need; and
- a nano-capsule beverage which contains nanoparticles encapsulated with specific flavours, colours or nutrients that can be activated with microwaves. The desired combination of flavours etc would be released by specific microwave frequencies.

3.2.3 Packaging

Storage is an important part aspect of the supply chain in the food industry as products move from the farm to the final consumer. For export markets, where products must be transported considerable distances over significant periods of time, correct control of storage conditions is crucial to maintaining food in good condition and for ensuring maximum shelf life, particularly for fresh and lightly processed food.

Packaging, either of individual food items or in bulk, is also important in maintaining product in optimal condition and retaining desired characteristics. The nanostructure of food packaging can be designed to ensure that the correct environmental conditions are maintained, so that chemicals given off by food and chemicals from the storage environment are both controlled.

Sensors embedded in packaging could report on environmental conditions and on the quality and condition of the food product. These sensors could perhaps take the form of surface coatings which change colour in the presence of pathogens or when food has deteriorated. Packaging containing these sensors could identify individual items that could be rejected rather than the whole batch.

Victoria has some prominent companies producing packaging materials, notable Amcor and Visy, which could use nanotechnology to incorporate desired properties in these materials.

3.3 Transport

3.3.1 Introduction

Transport equipment manufacturing – which encompasses the automotive, aerospace, shipbuilding and key supply industries – has major strategic significance for the economies of both Victoria and Australia because of:

- The strategic nature of the technologies employed, the intensive R&D that lies behind them, and the spillover effects to the rest of the economy associated with utilising these technologies;
- The economies of scope associated with the project management skills required in transport equipment systems integration has widespread spillover effects across both transport equipment and heavy engineering;

- The capacity of these industries to generate exports of elaborately transformed manufactures;
- The opportunities for employment of highly skilled and trained labour, facilitating an increased base for comparative advantage; and
- The complex nature of investments in this sector, particularly in aerospace and defence, with long payback periods and risk associated with technological uncertainty.

The nature of the technologies employed, and the intensive R&D that lies behind them, makes aerospace close to the most technology-intensive of all manufacturing industries. Of crucial importance are the spillover effects associated with the utilisation of these technologies. The synergies between civil and military aerospace are well known, and are currently expected to increase. The technological linkages between aerospace and shipbuilding, less well known hitherto in Australia (although well-appreciated in countries like Japan and Russia), are becoming increasingly important with the developing similarities between airframe and hull design and construction, and the extensive use of electronics.

In the longer run, given the increasing importance of new materials technology, aerodynamic styling and on-board electronics, these linkages could extend across the whole transport equipment sector, including motor vehicles. These technological interdependencies rest on the delivery of key technologies which are capable of transforming production in a range of industries – advanced materials (which have significance for aerospace, motor vehicles, shipbuilding, other transport equipment and building and construction), embedded information and communications technologies (aerospace, motor vehicles, shipbuilding, other transport equipment and transport system infrastructure), and aerodynamic design. Innovation in its broader sense also implies spillovers across the whole transport equipment and transport systems with respect to life-cycle design and manufacturing systems, maintenance and repair systems, and the development of a comprehensive approach to safety.

Defence contracts can provide a spur to technology in civil aerospace as well as other transport and engineering industries with respect to materials, electronics and on-board diagnostics. Civil aerospace, in turn, provides a lead to the defence sector with respect to computer-aided design and virtual prototyping, life cycle planning, maintenance and repair, and developments in air safety. The motor vehicle industry is a leader in lean manufacturing, but the new technological challenges it faces could eventually put it in the position of influencing industries like aerospace in particular technologies.

Finally, primary defence contractors, civil aerospace suppliers and motor vehicle producers depend on sub-contractors and suppliers of cast and forged metal products, repetition engineers, heavy engineers, and electronic sub-components. There is a two-way relationship here. The depth of the supply chain underpins the flexibility and capabilities of the major manufacturers. On the other hand, the major manufacturers often provide an important conduit for technology and productive efficiency to their sub-contractors. Technologies can also move in the other direction. In civil aerospace manufacturing, the integrators of the finished aircraft are shifting many aspects of design and R&D towards primary risk-sharing contractors. In the manufacture of aero-engines, new developments are taking place through the agency of complex international consortia.

There are economies of scope across a range of technologically advanced heavy engineering industries. The key aspect is systems integration, which requires state-of-the-art project management skills. In Japan, heavy engineering conglomerates have exploited these economies across aerospace, shipbuilding and civil engineering projects. In the United States the economies are exploited across civil and military aerospace and other defence projects. The motor vehicle industry has traditionally been more self-contained. US automobile producers have tended to shed peripheral interests over the past decade, although European companies such as DaimlerChrysler, BMW and Fiat still cover a wide range of interests. However, the new technologies being developed in the industry are leading to new associations between vehicle producers and innovative engineering companies.

Nano and micro technologies will have common applications across the different components of the transport equipment sector, especially in advanced materials technology, micro- and nano-electromechanical systems, vibrations dampeners, surface coatings, high-technology fabrics, MRO (maintenance, repair and overhaul) and advanced safety technologies.

3.3.2 The Automotive Industry

Future change in the world automotive industry is being determined by a number of different factors, including globalisation, excess manufacturing capacity, increasingly better-informed consumers, demand for improved vehicle safety and environmental concerns about air pollution, energy security and global warming.

Globalisation is reducing the extent of protected markets, excess capacity is sharpening competition, consumer awareness is intensifying competition on price, performance, features and reliability, new technologies are providing scope for increased competition on safety features, and environmental awareness is encouraging competition on environmentally sustainable technologies.

Intensifying competition results in pressures to boost productivity, to secure competitive prices and to improve vehicle quality. Innovation becomes the key to improving competitiveness, and accelerating technological change may be used as a competitive strategy to force rationalization of the global industry – increasing price competition, consumer amenity, safety, reliability, and facilitating improved environmental outcomes.
Intensifying competition and accelerating technological change is forcing structural change in the global automotive industry in two areas:

- The prime integrators who control design, the production process, marketing, and services are reducing in number, and consolidating in the USA, Japan and Germany (particularly around the major companies GM, Ford, DaimlerChrysler, Toyota, Honda and Volkswagen).

- The main production and assembly contractors and suppliers of parts and components are being driven by competitive pressures to share the rapidly rising costs of innovation and contribute positively to the innovation process, which in turn implies rationalization. The major production locations may not be the same as the location of the prime integrators over the longer haul. Some countries may increase their presence as manufacturers under contract or suppliers of parts and components, while other countries will face a contraction in the size and scope of their industries. The size of local markets (potential scale economies) and the depth and range of technological capabilities (economies of scope) will be critical factors in determining who wins and who loses.

The broader implications for Australia are that there are both threats and opportunities associated with intensifying global competition and accelerated technological change in which nanotechnology plays an important role.

The main threat relates to economies of scale and the size of the local market. Compared with a number of developing economies, the Australian automotive market is growing relatively slowly because of its maturity. In this context, the overall sector becomes vulnerable if there is an exogenous increase in the share of the market held by imports. This can reduce the size of the market below critical levels and lead to a contraction of the local industry in terms of the range of local production and the viability of key domestic suppliers. Such a process would discourage the local contribution to the innovation process (and capabilities in nanotechnology in particular) leading to concentration on pure assembly and a reduced role in the breadth of production across vehicle parts and components.

The opportunity confronting the Australian automotive industry and suppliers to the industry is to find new areas of specialisation based on the capacity to innovate and deliver in nanotechnology. The breadth of technological expertise, backed by research capabilities, provides a source of possible competitive advantage to be exploited.

Victoria is the base for the Australian automotive industry with an annual turnover of about $9 billion, employing about 30,000 people and being responsible for some 58% of production and 70% of Australian automotive R&D. The Victorian industry therefore would be the major beneficiary of transfers of new international technology into Australia, as well as the major loser if Victorian automotive plants are not able to keep up with the pace of global technological change. GMH, Toyota and Ford all have some developmental presence in the state. Victoria also has significant experience in harnessing a wide range of prospective technologies in producing developmental concept cars and solar cars. The depth of the nanotechnology base in Victoria would generally be assisted by developments across Australia in nanotechnology, as this would assist in leveraging such technology for use in the automotive sector.

Robert Bosch Australia has its headquarters and manufacturing plant located in Melbourne. Bosch Australia has overall responsibility within the international Bosch group for automotive original equipment in the ASEAN region and worldwide responsibility for development and manufacture of automotive on-board electronics. The company has significant expertise in R&D (employing more than 100 R&D engineers) and high tech manufacturing. It is probably the company best situated to enter the market for small scale electronic automotive applications.

Pilkington (Australia) Pty Ltd is a company in Victoria supplying glass to the automotive industry. Its parent company has developed a nanotechnology based self cleaning glass which will have applications in the automotive, building and other industries. The glass uses a photocatalytic coating which reacts with ultra-violet rays from natural daylight to break down and disintegrate organic dirt. It is also hydrophilic, so that instead of forming droplets the water spreads evenly over the surface, and as it runs off takes the dirt with it. Compared with conventional glass, the water also dries off very quickly and does not leave unsightly drying spots. Pilkington is also working on lightweight glazing, rain sensors for automatic activation of windscreen wipers, and other applications of small scale technologies

The principal areas where small scale technology will have greatest impact on the automotive industry are in:

- monitoring and control systems incorporating sensors and other electronics components; and
- new materials to improve performance and reduce cost.

Under these two headings, Box 2 summarises some of the main areas of technological innovation in the automotive industry where small scale technologies could have a major role within this industry.

Small scale technologies are likely to have a pervasive effect on the future of the Victorian automotive industry. Firms operating in the industry will need to become aware of, and proficient in, these technologies as they emerge. If this does not occur, the present position of the industry will not be sustained. On the other hand, if the major vehicles companies operating in Victoria, together with their local suppliers, can draw on local expertise to a leading position in some applications of small scale technologies to the industry, this will enhance Victoria's position in an industry that is heavily contested around the world.

Box 2. Potential Applications of Small Scale Technologies in the Automotive Industry

Monitoring and Control Systems

1. *Microelectromechanical systems (MEMS)*. (MEMS) are miniature sensors and motors about the size of a dust particle They can be implanted as indicators of stress and corrosion rates in materials, or on the surface of truck bodies to reduce drag and increase aerodynamic efficiency.
2. *Ignition*. High power switches in ignition devices.
3. *Electronics*. Nanotubes could replace silicon as a semiconductor. Other possibilities include the self-assembly of nanoscale electronic components, and nanoelectronics based on quantum effects.
4. *Flat screen display technology*. Carbon nanotubes could be used in electronic display screens.
5. *Advanced Virtual Reality design technologies*. These combine telerobotics (with nanotechnology in sensors), multimedia, computer-aided design, process simulation, ergonomics simulation (as in mannequin tools) and computer-generated imagery. These technologies increase the speed and reduce the cost of new vehicle designs.
6. *On-board diagnostics*. Nanotechnology incorporated into sensors and monitoring devices provides diagnostic indicators used to increase the efficiency of maintenance and repair activities in relation to mechanical parts and tyres.
7. *Environmental monitoring*. Sensors incorporating nanotechnology for the monitoring of the effectiveness of emission control systems.
8. *Automated vehicle control (AVC) systems*. AVC technologies are on-board technologies geared towards traffic safety. They can assist drivers in obstacle detection, anticollision sensing and infrared sensing for night driving. More advanced AVC technologies allow for automated driving. Nanotechnology has a role to play in the sensing devices used in this technology, and in advanced radar technology.

New Materials to Improve Performance and Reduce Cost

9. *Materials technology*. New, light weight and stronger materials – such as surface coatings, ultra-strong lightweight materials, and thin layers on bearings and gliding elements. Uses in vehicle bodies, suspensions, brake fittings, sway bars and wheels.
10. *Engine technology*. Compact fuel cells for use in new energy-efficient engines. Advanced batteries and supercapacitors for energy storage in hybrid electric vehicles. New types of solar cells for use in surface coatings, as an auxiliary source of energy.
11. *Motor parts*. New ceramics incorporating nanotechnology used in motor parts.
12. *Catalysis*. Nanoparticles for use in catalytic processes are relevant to improved internal combustion exhaust control.
13. *Vibration dampeners*. Improved vibration dampeners based on magnetic nanofluids.
14. *Filters*. New electrostatic filters incorporating nanotechnology.
15. *Coolants*. The use of nanofluids in new types of coolants.
16. *Paint additives*. Nanoparticles as paint additives to get new coloration effects and greater hardness and durability in materials.
17. *Plastics*. Nanotechnology used in new plastics that have greater strength.
18. *High technology fabrics*. Nanotechnology can be used to bind fibres tightly enough to be resistant to dirt and water. The conductive property of fabrics used in car seats can be improved by the use of nanoparticles of metals such as silver and nickel.
19. *Glass*. Nanotechnology can be used to control the optical properties of glass to pass only desired frequencies of light and provide self-cleaning properties.
20. *Green manufacturing technologies*. Nanomaterials can be used to replace toxic reagents and to reduce waste (so-called 'exact' manufacturing).

3.3.3 The Aerospace Industry

The global aerospace industry is heavily concentrated in the USA and Europe with Boeing and Airbus being the two dominant companies.

The main impetus to innovation in aerospace technologies is coming from four sources:

- increased competition in the airlines industry is driving demand for cost-effective aircraft performance combined with enhanced passenger facilities;
- the medium-term trend towards increased air traffic volumes necessitates increased focus on the safety of aircraft and aircraft operation;
- concerns about the environmental impacts on technology development in such areas as emissions reduction and reduced noise; and
- the resurgence in technological development in the defense industries.

The main areas of technological innovation in the aerospace sector are aerodynamics, materials, engines, electronics, design and manufacturing technologies, maintenance and repair, and safety.

Advanced Virtual Reality design technologies will be of major importance in the development of design and manufacturing technologies, and will assist in the development process associated with breakthroughs in aerodynamic design. Nanotechnology is heavily involved in new generation materials technology and this is likely to have applications in many areas of the industry, including airframes and engines. New energy technologies may eventually play an important role in engine developments, although this is a very long way off in the future. Nanotechnology is of critical importance to future advances in aviation electronics technology. Technological change in the maintenance, repair and overhaul business will incorporate small scale technologies such as MEMS and on-board diagnostics. Safety strategies will also make use of these emerging technologies in several areas. A summary of aerospace applications for small scale technologies is set out in Box 3.

The Victorian aerospace community includes the following companies and research organisations.

Boeing Australia is represented in Victoria through ASTA Engineering at Fishermans Bend and Hawker de Havilland in Fishermans Bend and Bayswater. ASTA is contracted to provide engineering support services to the scientists and researchers at the Defence Science and Technology Organisation's (DSTO) Aeronautical and Maritime Research Laboratory (AMRL) facility. This includes mechanical design and engineering, electronics design and engineering, applied imaging and photography, and manufacturing and model making. Hawker de Havilland is engaged in the design, tooling, manufacture and testing of airframe components and assemblies using advanced composites and/or machining and metal fabrication. Primary customers include Airbus UK, Alenia, BAE Systems, and Boeing (it will be promoted to a Tier 1 primary structure supplier to Boeing (US) in 2004).

Melbourne is the centre for aeronautical R&D activities and has a good supply of aeronautical engineers and skilled tradespeople. The RMIT Sir Lawrence Wackett Centre for Aeronautical Design, located at Fishermans Bend, is Victoria's foremost centre for aerospace education and research. The DSTO/AMRL R&D centre is also located at Fishermans Bend. GKN Engage, a division of the UK multinational company GKN Aerospace Services, has a design and analysis facility at Fishermans Bend offering engineering services to meet demand created by the launching of such new aircraft designs as the Airbus A380, the Airbus A400 military transport and the Joint Strike Fighter. GKN Engage ties its engineers together through its Virtual Design Team concept.

Box 3. The Emerging Role of Small Scale Technologies in the Aerospace Industry

Monitoring and Control Systems

1. *Microelectromechanical systems (MEMS). MEMS* could be used in aircraft wings, to reduce drag and increase efficiency as sensors for monitoring adhesive bonds critical to the structural integrity of aircraft; as smart autonomous strain gauges to monitor strains in critical areas of aircraft structures; as sensors for corrosion rates; as detectors for cracks in aircraft structures; as accelerometer arrays to displace existing gyroscopic technology, and as micro inertial measurement and navigation units for weapons guidance and control applications. These MEMs technologies are of major importance also for retrofitting and maintaining older aircraft.
2. *Avionics*. Particularly important in relation to navigation, air traffic control and visual display systems. Nanotechnology use in communications and display systems will facilitate the development of continuous tracking systems, using global automatic dependent surveillance based on GPS satellites and satellite navigation.
3. *Electronics*. As in the automotive industries, electronics is of increasing importance as a source of final product in aerospace, with fly-by-wire systems, auxiliary power systems and passenger entertainment being key areas of importance for electronics. Many of these factors are very important in military aerospace. Advanced conventional electronics, and quantum and molecular electronics as well as quantum optoelectronics, will become important.
4. *Advanced Virtual Reality design technologies*. The aerospace industry is likely to become a leader here, building on existing expertise in particular components of the technology.
5. *On-board diagnostics.* Potentially very important for defence as well as civil aerospace.
6. *Safety technologies*. The development of smart alerting functions which coordinate cockpit safety system alerts, particularly in relation to impending collisions, and which use advanced sensor technology. Advanced ground collision avoidance systems.

New Materials to Improve Performance and Reduce Cost

7. *Materials technology.* New and lighter weight and stronger, fire-resistant materials. Examples include ultra-strong lightweight nanocomposite materials, additives to improve the adhesion of parts and layers. New materials have a key to play in airframes and auxiliary equipment.
8. *Energy technologies*. Auxiliary power through compact fuel cells or new types of solar cells. Advanced materials technology can be used in the development of new aero-engines, including engine components.
9. *Surface coatings*. Aerodynamic, low-friction coatings. Anti-static coatings. Spectral signature coatings for camouflage or unique identification applications.
10. *High technology fabrics.* Improved properties for interior fittings.

BAE Systems Australia employs 2500 people. It has its centre of operations and mechanical and electronic manufacturing in Adelaide, but supports customers at more than 50 locations across the country, with its major operations in Adelaide, Sydney (communications and naval business) and Melbourne. Its main operations are in avionics and defence. BAE Systems does developmental work on high frequency semiconductor devices, multiple sensing platforms, and digital mapping of the ground surrounds of air routes.

Quantum Precision Instruments Pty Ltd is a nanotechnology company developing atomic precision sub-nanometer and sub-nanoradian positioning metrological devices for ultra-high precision positioning and nanoelectromechanical systems. Its markets are in micro-electronics; telecommunications; medical; acoustic applications in medical, security and defence industries; accelerometers in aviation, defence and automotive; seismic detection in mining; consumer electronics; and precision engineering. The company has been in operation for four years. It is based in West Footscray, with offices in Washington D.C. The Melbourne Integration Facility of RLM Systems is based in Burwood East.

This breadth of expertise in the Victorian aerospace industry which could be used the exploit the potential that small scale technologies offer the industry. Some examples include:

Materials technology. Advanced contracting work in the supply of airframe components and parts has been a feature of the Australian aerospace industry, and this implies competitiveness in materials technology. The Australian aerospace industry has considerable experience in both composites and lightweight metal alloys. Boeing Australia in Melbourne has a partnership with DSTO involving advanced composite structures. The company is also a participant in the CRC for Advanced Composite Structures. The CRC for Cast Metals Manufacturing is undertaking research in Victoria on the use of novel lightweight alloys.

MEMS. Quantum Precision Instruments has capabilities in the production of accelerometers and gyroscopes for aviation and defence. DSTO is conducting extensive research into a range of applications for MEMS technologies with applications to defence technology and implications for commercial aerospace. The new technologies have been licensed to small start-up companies in the United States; these companies are marketing small corrosion sensors for use by Boeing (US) in airframes.

Avionics. BAE Systems has its major operations in avionics, with expertise in sensors, electronic warfare, avionic systems (both civil and defence, including inertial systems). Boeing Australia has considerable expertise in the integration and manufacture of military avionics, navigation, command and communications systems, and conducts research on communication systems.

On-board diagnostics. The Structural Monitoring Systems technology has been developed in Australia. It provides detection of structural cracking in aircraft for both materials and composites. The aerospace industry provides the most immediately important market for such technology. MiniFab located at Scoresby is Australia's first applied research facility for testing and production of plastic micro-devices and is developing sensors to find cracks in aircraft.

Electronics. There is considerable defence-related expertise and some civil expertise in BAE Systems (particularly defence-related electronics), Boeing Australia (electronic systems design), Tenix Defence, Honeywell Australia, and Ericsson Australia. RLM Systems Pty Ltd specialises in software architecture development, design, production, integration, test and support of large, complex, leading-edge systems requiring advanced electronics and sophisticated software, with both commercial and defence clients in Australia and in the Asia-Pacific region, with a major Melbourne Integration Facility (MIF).

Continuous innovation is a characteristic of the aerospace industry, both among the major integrators (Airbus and Boeing) and the prime contractors to the integrators. The prime contractors are increasingly involved in the process of continuing innovation and their contracts often require ongoing improvements. The Australian aerospace industry has a significant track record in utilising new technologies in key contracts with Boeing and Airbus, such as the use of composite materials. While the domestic market for commercial aircraft is relatively small by world standards, the Australian market for technologically advanced defence aerospace is quite important. Moreover, the depth of aeronautical engineering expertise in Australia makes it an internationally competitive player for new aerospace contracts. Provided firms operating in Victoria are able to keep abreast of developments in small scale technologies they have real opportunities to participate in the development of new aerospace projects.

3.3.4 Shipbuilding

The shipbuilding industry in Victoria is much smaller than the automotive and aerospace industries but is a significant component of the defence manufacturing industry. As noted in the introduction above, shipbuilding has similarities to the aerospace industries, particularly in the manufacture of complex, technically sophisticated products. Ships and submarines produced for the Australian armed forces are likely to incorporate small scale technologies in the future, with examples of application areas as follows.

Materials technology. New stronger and less corrosive materials in ships and submarines.

MEMS. Smart autonomous strain gauges to monitor strains in inaccessible and critical areas of submarine structures Arrays of smart gauges for welds in submarines. Corrosion rate sensors for a broad range of vessels.

Engine technology. Auxiliary power for vessels through compact fuel cells or new types of solar cells. Utilisation of aerospace engine technology in ships, including advanced materials technology in engine components.

Vibration dampeners. Improved vibration dampeners for ships based on magnetic nanofluids.

Paint additives. Nanoparticles as paint additives make ship hulls more fuel efficient because barnacles cannot latch on and create drag, and they replace tin- and copper-based paints that leach toxins into the ocean.

High technology fabrics. Improved properties for interior fittings.

Electronics. Advanced micro-electronics and nanoelectronics based on quantum effects will have applications in defence and commercial shipping where electronics finds increasing applications. Boeing Australia produces fully integrated submarine communication and combat systems, and ship communication systems.

Flat screen display technology. Carbon nanotubes could be used in electronic display screens.

Advanced Virtual Reality design technologies. These technologies will increase the speed and reduce the cost of design improvements in commercial and defence shipping.

On-board diagnostics. Has implications for defence and civil shipbuilding.

Safety technologies. The development of smart alerting functions using advanced sensor technology for vessels.

Victorian capabilities in materials technology, MEMS, and electronics/avionics may provide future prospects for the exploitation of nanotechnology in marine engineering across Australia.

3.3.5 Other Transport

Nanotechnology may be particularly relevant for two areas: transport management and related services, and logistics.

Transport Management

There are applications for micro-electronics in advanced traffic management techniques, electronic road pricing and tolling, and advanced traveler information systems. BAE Systems is in partnerships producing integrated vehicle management systems. RLM Systems has developed a passive video detection system employing a network of camera sites to optically classify vehicles and capture images.

Logistics

Nanotechnology can be used for integrated sensor/GPS modules used in logistics for tracking goods. It is also important with respect to security and fleet management. BAE Systems has participated in the NexGen logistics development project. Alcatel provides convergent network solutions and interaction management to transportation companies.

3.4 Energy and Mining

3.4.1 Energy

Australia has an abundance of energy resources which make a significant contribution to the nation's exports and are inputs into the production of value added products based on these resources. Black coal for power and metals production is found principally in New South Wales and Queensland, while Victoria has extensive deposits of brown coal. Oil and gas are produced from reserves in a number of States both on-shore and off-shore. Electricity production is largely based on coal and gas, and is used in electricity-intensive industries such as aluminium production.

Australia's specialisation in energy production and utilisation means that it faces serious pressure to reduce greenhouse gases (GHG) and other emissions. This is particularly important for Victoria because brown-coal based electricity production has the highest GHG emissions per unit of energy generated of virtually all electricity generation techniques.

While demand side management can play a role in meeting GHG targets, the industry is looking at ways to make traditional electricity generation more efficient and to reduce losses in the transmission and distribution networks. New energy technologies such as solar power, biomass- and wind-based generation will also play a role in reducing emissions and meeting GHG targets.

Small-scale technology is expected to have applications in the many aspects of both the conventional and alternative energy generation, distribution and storage industries. In traditional large-scale centralised power generation the applications are likely to include the following three areas:

Sensors and controls in energy plants. Sensors and controls increase the efficiencies of equipment and processes, thus reducing energy use and related emissions. Industrial process control and energy management are continuously evolving, with new and improved sensors and advances in information processing technologies. Sensors and controls can also be important in monitoring the safety of energy structures.

Power electronics. Power electronics serve to upgrade power from distributed and intermittent sources to grid quality and to iron out disturbances to the grid that could result from end-use electro-technologies such as variable speed drives. Smaller, lighter, more efficient, lower-cost inverters are required, and reliability, cost and electromagnetic compatibility must be improved; there will be a role for nanotechnology in achieving such a technological breakthrough.

Transmission and distribution. The first practical superconducting power cables are now being installed. Superconductivity – the ability of a material to conduct electricity without losses due to resistance – is becoming feasible thanks to the discovery of materials (ceramics) that will do so above the boiling-point of nitrogen. Nanotechnology is likely to contribute further to the development of materials that are superconducting at higher temperatures. Electricity losses through transmission are huge, and superconducting cables could transmit large amounts of power with low losses. Improved transmission methods would have major environmental benefits and provide a relatively cheap way to meet the rising demand for power.

In terms of alternative energy systems, there are also likely to many applications of emerging small scale technologies, including the following.

Solar cells. Second-generation technologies making use of nanotechnology will replace current photovoltaic production based on crystalline and amorphous silicon technologies, and offer the potential of significant reductions in cost and/or improvements in efficiency. Molecules and bio-molecules can be used to absorb and transfer photonic energy to chemical energy, with application for solar energy conversion. The possibility of third generation thin-film solar cells is now being explored.

Fuel cells. The development of fuel cells, still in its infancy, could be affected significantly by nanostructured catalysts and by structuring their components at the nanoscale (for example, by the use of nanotubes). This could lead to very small fuel cells for mobile phones, laptops, and other electronic equipment, and for defence, transport and remote area applications.

Other energy storage systems. Work is also progressing on advanced batteries and capacitors using nanomaterials. One major potential change in batteries is a very substantial increase in charge and discharge rates.

Fuel processing. Improved technologies are becoming available that use modified surface properties for bioreactor processing of gasohol based on hydrocarbon fuel replacements. Improved separation technologies (using nanotechnology membranes) in the generation of hydrocarbon replacement fuels also seem likely.

Catalysts. A catalyst is a substance that initiates or enhances a reaction without itself being used up in the process, and they are currently used in a wide variety of products. Because a catalyst has its effect through surface contact, and as the surface/mass ratio rises as a particle gets smaller, advances in nanotechnology promise much improved catalysts. These are likely to have a major impact on the energy and fuel industries, and in many other industries.

Victoria's large-scale power generation based on brown coal has the highest rate of greenhouse gas emission per unit of power of all coal based electricity processes. The industry is under great pressure to reduce emissions and has invested heavily in R&D in this area. In addition, the Commonwealth Government has required that 2% of all electricity generated be sourced from renewable energy generation. Victoria's energy industry could be an early adopter of nanotechnology in both energy savings through better control of generation, distribution and storage and through its application in alternative energy systems. An example of the latter in Victoria is Ceramic Fuel Cells Limited (CFCL), which was established to further develop and commercialise solid oxide fell cell technology developed by the CSIRO. In the longer term, small scale technologies could transform the production, distribution and use of energy in Victoria.

3.4.2 Mining

While mining is a relatively small industry in Australia in terms of employment it is an important contributor to exports and national wealth. While most mining in Australia is done on Queensland, Western Australia and New South Wales, Victoria is still the home to a number of major mining companies and significant industry research is conducted in the State. In addition, mining of brown coal provides the main feedstock to the State's electricity generation industry.

In the mining industry, nanotechnology could have applications in both monitoring and control of mining operations and in recovering metals from ores. Mining is increasingly an automated process with operators at some distance from the equipment. Remotely controlled sensors could be used to monitor conditions in mines and to report on damage and wear to mining equipment. Their use in such equipment would be analogous to that in the automotive industry. In addition, nanotechnology could be used to control the properties of mineral particles in separation processes used to extract metal from ores.

The use of nanotechnology in the above applications is just beginning in Australia.

In the field of sensors, the Victorian company Mindata uses micro-technology in accelerometers for geophysical measurement.

3.5 Computing and Communications

Microtechnology in large part utilises techniques developed initially by the semiconductor industry in the fabrication of microelectronic circuits and other devices. Semiconductor companies such as Motorola are interested in using this technology to manufacture novel microtechnology devices such as sensors and are supporting research in the CRC for Microtechnology in this area.

Current semiconductor manufacturing technology operates at close to nanoscale – around 0.13 microns or 130 nanometres – and requires investments in plant and equipment of billions of dollars. Microtechnology can use earlier generations of this technology at a fraction of the cost which brings the technology within the consideration of ICT and electronics companies in Victoria. These companies include large multinationals as well as smaller Australian companies. Some idea of the scope of these electronics companies is given in Table 3 below.

Table 3. Companies with Small Scale ICT and Related Activities in Victoria

Information and communications technologies	Siemens, NEC, Extel, Halipex, G&D, VPI Systems, Diamond Australia, RFS
Contract Manufacturing / PCBs	Precision Australia, AEMS, Labtam, Duet, Millison, Millinium, Clevertronics, EPDM
Instrumentation	Agilent Technologies, Gedge, Phasefale, Datataker, Hawk Measurement, Contrec
Medical	GBC, Varian, Medtron, Vision, Compumedics, Norwood Abby
Industrial and Process Control	ANCA, Datataker, Industrial Process Controls, Innovonics, Intermoco, Moonlighting, Neo, Robotron, Traffic Technologies
Security	Interlogix, Inner Range, Nidac, ACD Digital, Vision, Intelligent Fire Systems
Power supplies	Rectifier Technologies, Setec, Selectronic, Thycon, Thytec
Automotive electronics	Bosch, Siemens VDO, Australian Arrow (Yazaki), Denso (Flexdrive and AAA), Air International, AME Systems, PBR, Sumitomo

Potential applications of *small scale technology* in electronics and computer technologies include:

- Nanostructured microprocessor devices that continue the trend in declining energy use and cost per gate, thereby potentially improving the efficiency of computers by a factor of millions;
- Higher transmission frequencies and more efficient utilization of the optical spectrum to provide at least ten times more fibre bandwidth, with consequences in business, education, entertainment and defence;
- Small mass storage devices with capabilities at multi-terabit levels, a thousand times better than today;
- Integrated nanosensor systems capable of collecting, processing and communicating massive amounts of data with minimal size, weight, and power consumption; and
- The further development of hybrid semiconductor devices incorporating sensors and communications systems, such as RF.

The first of these areas covers novel integrated circuits and switching devices as well as molecular electronics. Practical applications of these are likely to be some way off but Victoria does have some relevant research expertise. The Melbourne node of the Special Research Center for Quantum Computer Technology at the University of Melbourne is working on techniques for placing single atoms in quantum wells within semiconductor substrates. This could form the basis of a quantum computer with massive increases in computing power. Nearer term applications include building traditional semiconductors at smaller dimensions and this is being actively pursued with manufacturers.

The Industrial Research Institute at Swinburne University is undertaking work using technology originating in semiconductor manufacturing to construct arrays of living neuronal networks and their integration on microchips. As well as constructing computing devices based on this, other applications include biomedical devices, very sensitive biosensors, and drug screening.

While the opportunities for Victoria to participate in the mainstream microelectronics and nanoelectronics industries may be limited in the near future, microfabrication infrastructure similar to that used in these industries is a major necessity for participation in most areas of microtechnology such as sensors and other devices.

3.6 Environmental Industries

The environmental industries can be defined as those companies providing goods and services that are involved in monitoring, managing, protecting or remediating the air, water or land environments. However consideration of environmental impact is a significant aspect of most industries, especially in agriculture, mining, manufacturing (chemicals, food processing), construction, utilities such as electricity generation and water and sewage supply and other service industries such as health and defence.

The application of small scale technologies to environmental products is therefore likely to have impacts beyond those within the environmental industries per se.

Applications of nanotechnology within the environmental goods and services sector include

Sensors for monitoring the environment (air quality, surface and groundwater, coastal etc.) and for control of environmental services (irrigation, pollution control and waste management, water quality).

Nanoscale membrane filters and other treatment aids for the water industry (technologies addressing the purification of water supplies; surface modification to address fouling by bacteria and algae, separations technology to minimise biofouling in the supply of pure water in regions of high salinity).

Nanoparticles for use in emission abatement (catalysis for air and water pollution), waste management (nanoporous materials that trap contaminants) and remediation (nanofiltration methods).

Contribution to new manufacturing processes that are more environmentally benign, in particular, reducing waste through ‘exact manufacturing’, using less toxic and renewable reagents and processing materials, and the production of more environmentally benign manufactured products.

While some promising research on applications of nanotechnology for the environmental goods and services industry are being pursued in Australia, there is only a little evidence of take-up of such technologies by industry. Activities by some prominent Victorian companies in this industry include:

- Vivendi Water (water industry) utilises nanotechnology, drawn in part from its subsidiary Memcor Products;
- Collex (waste management) uses advanced membrane technologies for separation of industrial waste derived from research of the French parent company, also likely to use advanced local technologies, but not aware of nanoscale membrane technologies; and
- Mindata (scientific instruments for geotechnical and environmental industries) – sensors by bulk using traditional technologies, microtechnology for pressure sensors (water levels) just coming in.

3.7 Chemicals and Materials

This is currently the major area of commercial applications of nanotechnology and is likely to remain so in the short-term future.

The drivers of change in these industries are interlinked. In the case of chemicals, there is a need to meet stringent environmental standards by developing cleaner production processes and to cut costs by improved process technology. Improved catalytic materials are significant in this regard. Further, the production of common chemicals has moved to large-scale plants in low labour cost countries and chemical companies in developed countries are looking to retain viability by moving into production of fine chemicals with high added value e.g. ceramic powders. This trend is exemplified by Japan. In Australia chemical production is rapidly losing its viability and companies are looking for other investments; production of nanoparticles or carbon nanotubes could be an option although demand may not be on the same scale as for mainstream chemicals.

Materials are ubiquitous throughout the industries covered in this report. The applications are almost limitless in terms of improvement of existing materials and in the creation of new materials. The drivers of change are production of stronger, 'smarter', lighter and environmentally friendly materials. They are not necessarily cheaper but give better value for money than present options. The requirements differ across industries and there is thus a broad spectrum of possibilities. On the local scene, applications in industries such as packaging and paints have already made impacts and potential applications are noted elsewhere in this report.

The main interest of industry overseas is in suitable production methods for low-cost, reproducible manufacturing materials (nanoparticles, nanoporous systems, corrosion inhibitors, polymers, molecular sieves, ceramics, light absorbers and emitters, magnetic nanomaterials, pigments and colloids). For example, the global market for nanoscale powders in conventional applications such as ceramic glazes, carbon black for tyres and other functional coatings such as paints was worth US$42 billion in 1998 and is expected to quadruple by 2004.

Nanoparticles can be produced by various techniques, either ‘top-down’ by milling or cutting bulk materials or from ‘bottom-up’ by precipitating from the vapour phase or from liquids. An example of an Australian development in nanomaterials which illustrates how properties change at the nanoscale and how these can be utilized to develop a market is that of zinc oxide powders for use in sunscreens. Conventional sunscreens are based on either chemical absorbers or physical barriers. The former have the advantage of being transparent and cosmetically acceptable but are less efficient than the latter. These are based on zinc oxide which with the large particle sizes normally used have a dramatic whitening effect. Further the quantity of zinc oxide is only about 6 to 7 per cent and must be applied thickly for protection.

By reducing the particle size to the nanoscale, say 5-10 nm, the absorption characteristics for UV and IR radiation change and it is possible to create a sunscreen that is transparent and also contains a higher content of zinc oxide (up to 40 per cent) which is thus more effective as a blocking agent. This range of particle sizes can be obtained by milling using additives to change particle size and ensure dispersion.

Two companies, Advanced Nano Technologies in Western Australia and Micronisers in Victoria, have independently developed such technologies and are marketing the product in Australia and overseas. Further, Advanced Nano Technologies has linked to Samsung Corning in South Korea to develop cerium oxide nanopowders which will be used for slurries to polish microchips. Major production will take place in Korea under licence with targeted sales of US423 million by 2005. Other ceramic materials are under development.

Many conventional materials such as metallic alloys, ceramics and polymers gain added strength by dispersing nanoscale particles in a matrix. In metallic alloys these nanoparticles are precipitated from solid solution by heating to a high temperature and by controlling the cooling rate. Another technique is to take mixtures of powders, shape them by pressing and then sinter at high temperatures to form strong solids. By using nanoparticles it is possible to create materials having novel electrical, magnetic and mechanical properties.

By adding nanoparticles to polymers during processing it is possible to improve properties such as strength but also to alter optical properties such as light transmission. The current world market for nanoparticles is estimated at about US$300 million but an optimistic prediction is up to US$1.5 billion by 2010. The bulk of this will be in low-cost composites using nanoscale clay particles which can be produced at A$15-25 per kg. The markets for these are in the construction sector but also in packaging and automotive industries. They are principally used for weight reduction but by using suitably reactive clays it is possible to control deterioration of fruit and vegetables during storage in clay nanocomposite packaging. This is potentially a major growth area in Victoria and CSIRO is working closely with the local packaging industry.

Stronger nanocomposites can be produced using other additives e.g. carbon nanotubes but the cost is currently prohibitive with carbon nanotubes at about $30 per gm. The coatings industry is a growing area for use of nanoparticles. Conventional coatings can have their properties enhanced or radically altered by using nanopowders.

A new Australian company, Bottle Magic, uses a novel glass bottle coating technology containing nanoparticles developed in conjunction with CSIRO to prolong shelf life and to offer new packaging possibilities.

Paints can also be improved by using nanoparticles. Orica Australia in Victoria has developed novel latex polymer technology to produce 100 nm particles which confer improved properties for wash-and-wear paints. This technology has potentially wide applications.

Ultrathin coatings produced by deposition are another area for nanomaterials applications. The world market was estimated at US$25 billion in 2001 and is anticipated to increase to US$80 billion by 2010.A major application is in the ICT industry for data storage media and components. From a Victorian industry viewpoint, improved hard coatings and optical coatings are possible areas for application. Considerable interest is being shown overseas in functional coatings such as easy-clean surfaces and surfaces with switchable properties with application in the construction or transport industries.

Catalysts are a major area for application of nanomaterials. They are already used in the production of a wide range of pharmaceuticals, chemicals and fuels and in emission control systems for environmental control. The world market is currently around US$30 billion and is expected to reach US$100 billion by 2015. This growth will be driven by improved understanding of design of catalytic materials. Given the relatively small industry base in Australia developments will come from overseas but adaptation to Australian conditions will be needed.

Carbon nanotubes represent an exciting new class of nanomaterials with a wide range of properties and potential applications. They have remarkable strength (up to 100 times that of steel), can be electrical conductors or semiconductors, and are excellent conductors of heat. Given the potential applications in super-strong composites, nanoelectronics, sensors and nanofiltration, numerous pilot plants have been set up overseas with several in Japan. Small quantities have been produced on a laboratory scale in Australia. The key to wider applications will be substantially lowered costs and better characterization of nanotubes and, in nanocomposites, better methods of dispersion. There could be niche industry applications in Victoria if industry were alerted. Recently questions have been raised over the toxicity of carbon nanotubes when ingested and this may necessitate special manufacturing facilities.

3.8 Building and Construction

In the building and construction industry, nanotechnology is likely to emerge in the following areas.

High-tech coating materials such as carbon nanotube-filled conductive composites in construction and manufacturing coatings.

Ultra-strong lightweight materials could be used for special applications and new materials could be developed for improved insulation, fire protection and other uses.

Nanotechnology-based home and office lighting is possible using light conducting polymers.

Sensors could have ubiquitous use in buildings if they can be made cheap enough using small scale technology. They could be implanted in structural building materials and be used for environment control.

Glazing which controls the optical properties of glass to pass only desired frequencies of light, and blocking damaging infra-red and ultra violet frequencies. As noted in the section on the automotive industry, self-cleaning glass has already been developed by Pilkington and is being used in buildings

Energy, advanced solar energy systems to improve the energy efficiency and environmental impact of the built environment.

In Victoria, CSIRO Materials Science Division has expertise in high-tech coating materials. The inclusion of nanoparticulate materials in a paint mixture can produce dark coloured paints which do not get hot and light coloured paints that do not glare. Dulux, based in the Melbourne suburb of Clayton, has patented its Wash & Wear 101 paint using nanotechnology in the form of small polymer particles.

The UTS Institute for Nanoscale Technology, jointly with the CSIRO, has launched a Nanohouse Initiative. This is a collaboration between Australian scientists, engineers, designers and builders working together to design and later build a new type of ultra-energy efficient house exploiting the new materials being developed by nanotechnology. The long-term objective is to showcase the house in the form of a mobile exhibit version at a large number of events across the world in a manner analogous with that used in the aXcessAustralia project. The core staff will be located at UTS City Campus at Ultimo in Sydney and also in various divisions of CSIRO, in both NSW and Victoria. Some of the types of technologies that are under consideration for incorporation in the house include:

- Advanced windows technology with UV/IR filtering and reflecting through nanoparticle-doped polymer films applied to glass and self-cleaning TIO_2 coated glass;
- Protective coatings (lacquers for example) for furnishings doped with Z_nO nanoparticles offering UV protection;
- Food containers using polymers with tuned optical properties for the enhancement of shelf life of both containers and contents;
- Lighting systems – polymer light pipes for the harvesting of daylight and ultra efficient bright white LED light sources at night;

- Water quality control systems – nano filtration via nanoporous materials for the removal of pollutants from water, used in combination with nano biological methods of cleaning effluent water;
- Textiles – clothes and other textile-based products with nano-engineering to reduce the need for washing with detergent; and
- Paints with nanoscale additives to control unwanted glare (from light coloured surfaces) and also some dark pigments that do not retain heat.

Victorian technological capacity is present with respect to paints (Dulux) and glass (Pilkington). The Nanohouse Initiative is expected to have some activities in Victoria.

3.9 Security and Defence

The technology developed by the US has led to a revolution in warfare as instanced in the conflicts in Afghanistan and Iraq. A significant driver of change has been strong public opinion, expressed in the legislature by increased financial commitments, to minimize US casualties and also enemy civilian casualties and to maximize the impact on enemy soldiers. This has been achieved by 'smarter' munitions, improved information systems, better-armoured vehicles and aircraft, and improved personal protection. In all these areas small-scale technology has a role to play, often in a dual role where military technology can be transferred to civilian purposes. On the local scene the increasingly close linkages between the Australian and US forces means that such technologies will be introduced here in the near future and opportunities for local production of some items, particularly personal protection, will be opened up.

The defence industry worldwide is already spending large amounts on applications of nanotechnology: much of this is 'dual-use' technology which can be used in civil applications but cost will determine the extent. As an example the US Army has established a special unit, the Institute for Soldier Nanotechnologies at the Massachusetts Institute of Technology, to develop new applications. One area is the development of smart uniforms which not only relay information on the condition of the wearer such as stress levels but can respond to physical trauma by administering treatment in response to sensors built into the uniforms. Such materials could have application in outdoor extreme sports. Another area of research is fibres reinforced with carbon nanotubes to replace Kevlar in bullet-proof vests with considerable weight reduction and thus increased mobility for the wearer. This could have applications for police and security personnel.

New sensor technologies based on biosensors, nanowires and quantum dots are being extensively examined for the rapid detection and identification of both chemical and biological agents on the battlefield. The aim is a cheap and expendable system which can be dispersed rapidly. Such sensors have applications in civil defence against bio-terrorism. The CRC for Microtechnology is exploring biosensors that which could be suitable. The sensors are cheap but the equipment needed to read them is more expensive and offers opportunities for possible industry development in Victoria.

4. Policy Responses

4.1 Global Trends and Local Realities: Implications for Victorian Policy

The first three sections of this report have established a number of conclusions about small scale technologies that have important implications for science, technology and industry policy in Victoria. Some of the main points are noted below.

(i) The convergence of the physical and biological sciences at the atomic level, and the extension of this convergence to the engineering and electronics industries that both support the sciences and flow from them, will transform scientific knowledge over the next few decades.

(ii) The application of this new knowledge in technologies at the micro and nano scale, and the integration of such small scale technologies into everyday products and processes, will have widespread ramifications throughout most of the economic system.

(iii) Recognising these facts, governments around the world, especially in North America, Europe and East Asia, have embarked on a major round of new programs to support small scale science and related technologies. In the three regions mentioned, government support for small scale science and technology will be in excess of A$5 billion in 2003.

(iv) Over the longer term, as nanotechnology develops the capacity to create new forms of matter and self-replicating mechanisms, deep moral issues will arise about the development and application of such technologies. These require mature and careful consideration by the human community, rather than the headlong pursuit of any technology that becomes available.

(v) The impact of small scale technologies on firms, industries and jobs in Victoria will be substantial over the next one to two decades. This impact is unavoidable, and will shake the competitive position of firms and the structure of industries. But early recognition of this impact, and vigorous action to take a leading role in the application of these new technologies, could generate real economic and social benefits.

(vi) Victoria has a strong science base in fields relevant to small scale technologies, including biotechnology. But, inevitably, these are small pockets of expertise in global terms. Researchers are constrained by limited access to funding, to advanced infrastructure, to the global research community and to a pool of companies actively seeking to make use of small scale technologies.

(vii) While the impact of these technologies will be profound, both in industry and in social and economic life more generally, there is limited awareness within firms or within the wider community about this impact, or about means of responding to it.

It follows from these conclusions that the Victorian Government should undertake a leadership role to assist the community to come to terms with, and to prosper within, the emerging era of small scale technologies.

While it is important to strengthen the research base, the major opportunity for Victoria is in the application of emerging micro and nano technologies in many different areas of economic and social life. The review undertaken in Chapter 3 has shown how pervasive these potential applications are, and that in most cases they are still in the early stage of development. Many applications of micro and even nano technologies will be relatively low cost, certainly when compared with those in the semiconductor and pharmaceutical industries. This means that expertise, imagination and timeliness may be more important than scale in such applications. Victoria still has the opportunity to establish a central role in terms of the application of small scale technologies.

4.2 Objectives, Instruments and Institutions

In our view, then, the central objective of Victorian policy in this area should be to make the State *a leading centre for the commercial development and application of small scale technologies by firms, public agencies and other organisations, in the context of sustained and shared reflection on the social and ethical issues involved.*

Many of the nanotechnology initiatives in other countries are directed primarily at the scientific foundations of nanotechnology, although they often take place in the context of much more extensive links between scientific research and business firms than exist in Australia. While the development of high level scientific capability in Victoria remains critical, most of the path-breaking scientific work on nanotechnologies will inevitably be done in the major centres of North America, Europe and East Asia. New Victorian support activities should be directed at small scale technologies more generally, and at the commercial application of these technologies rather than at further strengthening the research base per se. However, if Victoria can develop a strong base of firms actively exploiting small scale technologies, this will have major spin-offs to increased research activity. Links to the major scientific centres, and alliances with some of the main commercial players, will also be critical.

In our assessment, there are six main areas where policy initiatives are required, and where appropriate instruments need to be fashioned, to achieve this objective. The six areas are:

- *Facilitating Infrastructure*: working with firms and research groups, and international experts, to plan and implement the basic infrastructure required for the application of small scale technologies, and to review that infrastructure on a regular basis.
- *Raising Awareness and Demonstrating Applications*: implementing programs to raise awareness in firms and in the community about the implications of small scale technologies, for example by funding demonstration projects.
- *Building the Skills Base*: bringing together industry, universities and TAFE colleges to identify current or emerging gaps in Victoria's skill base for the application of small scale technologies, and to design and implement appropriate programs.

- *Encouraging Commercial Applications*: encouraging commercial applications of small scale technologies, through creation of Applications Development Consortia and in other ways;
- *Facilitating Alliances and Networks*: assisting local firms and research institutions to enter into alliances and networks with firms operating elsewhere in Australia, and in the USA, Europe and East Asia.
- *Strengthening Social and Ethical Reflection*: strengthening the capacity of the Victorian community to address, in a sustained and considered fashion, the social and ethical issues raised by small scale technologies.

These six areas are discussed below. To provide leadership in these six areas towards the achievement of the proposed objective, it is also recommended that a new peak body, here termed Small Scale Technologies Victoria, should be established. The nature and function of this body is discussed in Section 4.9.

4.3 Infrastructure for Research and Commercial Development

One central requirement for these objectives to be achieved is the creation of the infrastructure necessary for both high level research and for commercial development. Here we focus on the 'hard' infrastructure of structures, equipment and systems. But the 'soft' infrastructure necessary for competitive research and effective commercial development - such as institutions, organisations, attitudes, incentives and awareness - is even more important, and is discussed in subsequent sections.

Much is being done, with the support of State and Federal Government programs, to build the infrastructure for small scale technology research and commercial development in Victoria, but much more remains to be done. Recent significant activities include:

- the building of the Australian Synchrotron;
- the creation of the CRC for Microtechnology;
- the establishment of Bio21, MiniFab and NanoVic; and
- other activities of the universities, including the creation of the Centre for Nanoscience and Nanotechnology at the University of Melbourne.

Victoria's strength in biomedicine, recently expressed through the establishment of the National Stem Cell Centre at Monash University, is also highly relevant to future infrastructure needs.

In spite of these vital activities, Victoria's infrastructure remains well short of that necessary to allow it to become 'a leading centre for the commercial development and application of small scale technologies', and well short of that available in many regions around the world. But these recent initiatives, and the availability of funding sources such as the Victorian Government's STI program and the infrastructure programs of the Australian Government, mean that a world class infrastructure foundation can now be put in place in Victoria.

There is no simple specification of what is required to create such a world class infrastructure in Victoria. There is a complex, synergistic relationship between infrastructure, research and commercial development. A basic level of infrastructure is required to make both research and commercial development possible, and advanced infrastructure in a suitable environment will greatly stimulate both R&D and the application of new technologies. But the progress of R&D and commercial application will change and increase infrastructure requirements, while also increasing funding options. For these reasons the specifics of infrastructure requirements need to be a matter for continuing assessment, in the context of emerging research and commercial activities and in conjunction with those expert in these trends and their international context.

Even so, there is a need for some immediate investment to complete the basic infrastructure for research in, and commercialisation of, small scale technologies in Victoria. This will include improved facilities for the rapid design, development and prototyping of micro-devices, such as electron beam lithography and deep ion etching facilities, and for measurement and testing at the micro and nano levels.

A detailed review of immediate infrastructure needs, drawing on both local and international expertise, should be an immediate priority. Our initial assessment is that an allocation of about $30 million over the next 2-3 years from the STI fund should prove sufficient, if the funds are carefully used to leverage matching funds from industry, the universities and the Australian Government.

4.4 Awareness Raising in Industry: Demonstration Projects

This report has argued that small-scale technologies at the micro and nano scale are the outcome of natural progress within the mainstream scientific and engineering disciplines. Over recent decades scientists working in materials science, chemistry, physics and molecular biology and in biotechnology have gained greater control over particles and structures at these small scales. They have used this greater control to endow materials with new characteristics, and have designed and built increasingly complex structures for a wide variety of applications.

This ability to control activities at small scales can potentially change the characteristics of most products and processes that utilise the properties of particles and more complex small scale structures. Scientists and engineers are therefore really only scratching the surface of the potential for small-scale technologies which could become ubiquitous within a great range of new products over coming decades.

Victoria has a small but growing community of research groups with expertise in many of the relevant areas of small-scale technology. Yet the potential of these technologies to develop innovative products with new properties, to reconfigure existing products and to produce products at lower cost is largely unrecognised within mainstream Victorian industry, or within the community at large. This is so in spite of the fact that, when compared to other areas of advanced technology, such as semiconductor manufacturing, the costs of developing expertise in and adopting small-scale technologies are likely to be within the capability of most industries.

One challenge for both the Victorian Government and the research community, therefore, is to develop a greater awareness of the potential benefits of small-scale technology within Victorian industry and to encourage creative thinking within industry about how the technology can be utilised. This issue of fostering awareness should be addressed in many ways, such as by making small scale technologies a major focus of the Victorian Innovation Lectures to be held in 2004 and 2005, and also by establishing an extensive program of demonstration projects. Such a program would aim to show, through practical and concrete examples, the benefits that can be achieved through the application of small scale technologies. Some examples of potential projects within industries that are important to Victoria have been mentioned in Section 3, including Point-of-Care diagnostics for the health care sector and environmental sensor systems in high value-added agriculture, such as vineyards. The NanoHouse Initiative in Sydney is another example.

A Demonstration Projects Program could have the following characteristics:

- Projects would be invited from individual companies or consortia of companies.
- Projects must have as an outcome the development of an application of benefit to the company or companies, such as a new product or process.
- There should be similar applications potentially available in other companies and industries
- The project must utilise small-scale technology as a crucial part of the project, although other technologies can also be used.
- Project participants must agree to participate in a program publicising the results of the study, subject to reasonable confidentiality requirements.
- An agreed proportion of the funds provided by the Government must be used to employ researchers from the Victorian small-scale research community.
- There must be an up-front agreement on disposition of intellectual property developed during the course of the project.
- Projects could address priority industries or applications such as sensors, biomedical products, food processing, automotive applications, etc.
- Projects should be of a maximum duration, say three years, and a minimum size, say $3 million, of which only a proportion would be met by public funds. While any such constraints should be flexible, the central aim should be to support projects of a significant size and with reasonably early demonstration benefits.

To ensure that the program attracts quality proposals, it may be necessary to provide funding and other support to companies wishing to develop proposals, say to a maximum of $50,000 per proposal. A suitably designed promotional program within industry would support the demonstration projects program, preferably with the support of industry and professional associations and like bodies.

Industry development officers in the Department of Industry, Innovation and Regional Development, the Department of Primary Industries and other relevant Government agencies could participate in programs, both to raise the awareness of industry about the benefits of small-scale technology and to help in the development and assessment of proposals for demonstration projects. Consideration could also be given to employing suitable personnel for a fixed period within industry associations to promote awareness of small-scale technology and to assist in the development of project proposals.

4.5 Education and Training

While educational needs have been widely addressed overseas (e.g. Roco 2001), there is little systematic knowledge in the public domain of Victoria's education and training needs in relation to small scale technologies. However, as part of its ongoing assessment of the education and training needs of emerging industries in Victoria, the Department of Innovation, Industry and Regional Development has reviewed the skills requirements of the small scale technology sector. We draw on that unpublished review in this section.

The review noted that nanotechnology development, whether carried out in start-up companies or within larger established companies, will require generic entrepreneurship, management, communication and business skills, as well as the ability to work productively in multidisciplinary teams. There are already courses offered in these skills in most universities in Victoria, for instance at Swinburne University and at RMIT University. In addition, most students associated with the Cooperative Research Centre for Microtechnology participate in short courses that expose them to some of the commercial realities of intellectual property and start-up companies. Curriculum developers are also seeking to incorporate these skills into existing science and engineering courses.

Researchers in small scale technology have usually acquired their skills through the traditional disciplines of chemistry, physics, materials science, molecular biology, engineering, and information technology. Within these disciplines they specialise in small scale technologies in the final years of an undergraduate degree and in higher degrees.

Researchers in small scale technologies will typically be working in teams on projects that require a mixture of skills from different disciplines eg materials science and engineering, or molecular biology and information technology. It is important therefore that students intending to specialise in small scale technologies have some understanding of how other disciplines approach scientific research and where fruitful interaction is likely to occur. One of the obstacles to greater communication is the specialised terminology developed within disciplines and a common vocabulary would facilitate much easier interaction on joint projects.

Universities in other States (such as Flinders University, Griffith University, University of New South Wales and University of Technology Sydney) have begun to offer undergraduate courses leading to a degree in nanotechnology or nanoscience. It is expected that RMIT will offer a similar course in 2004, while Monash University is developing a nanotechnology stream within an undergraduate science degree. However, the IIRD review quotes some employers as preferring potential employees to have a strong grounding in traditional subjects such as chemistry, arguing that the specific nanotechnology skills can be acquired relatively quickly on top of these qualifications.

Small scale technologies will also require new and upgraded skills at the technician level as small scale technologies become increasingly common in industry. For instance, the development of specialised nanomaterials, such as nanocomposites and nanopowders, may have an impact similar in scope to the introduction of plastics and composites in earlier decades. This will require a substantial overhaul of certificate level courses in areas such as process manufacturing, engineering, chemical processing and powder coating. During the course of this study, several experts in small scale technology also pointed to the shortage of technicians and other people with certificate level qualifications, particularly in the case of technicians and maintenance workers for clean rooms.

Increasing awareness of the benefits of incorporating small scale technologies in new products and processes will create a strong demand for people with relevant expertise. However, there is insufficient current enrolment in disciplines relevant to small scale technology to meet existing demand from industry, let alone any future demand. These shortages seem to be particularly acute in chemistry, materials science and engineering, microprocess engineering and metrology. It would be appropriate therefore to dedicate more resources to overcoming potential students' poor perceptions of chemistry and materials science, by promoting their importance as foundation skills for the more glamorous fields of small scale technologies.

This awareness issue must also be addressed in schools, where the shaping of students' future careers takes place. The IIRD review found that there is significant interest amongst science teachers in secondary schools in incorporating nanotechnology in the science syllabus for VCE. The review identified the opportunity of developing a four week nanotechnology "Detailed Study" option for VCE Physics, Chemistry and Biology. It is important that small scale technology be addressed within secondary schools to spark the interest of students in pursuing it in tertiary education.

An interesting experiment is the Nanotechnology Centre grants awarded by the National Science Foundation to US universities. These grants specifically task the universities to link to local high schools and to develop learning modules and projects that encourage students to use advanced equipment in the universities. A similar program is being implemented in South Australia, with the Australian Science and Maths School being opened on the campus of Flinders University. These programs need to be evaluated and possibly adapted for use in Victoria.

- There is thus an important and urgent role for the Government in bringing together industry, universities and TAFE colleges to identify current or emerging gaps in Victoria's skill base for the application of small scale technologies, and to design and implement appropriate programs. The success of the Victorian Education Foundation, between 1987 and 1995, in working on a cooperative basis and with modest funding to reshape post-secondary courses to meet emerging needs illustrates one way in which this can be done (Williams 1995). The Williams Report showed that, over this period, the Foundation achieved a multiplier of nearly 2 to 1 in terms of funds from industry and academia committed relative to the expenditure of Foundation funds. It also demonstrated that ithe Foundation had a significant impact in assisting the development of educational programs in areas of identified need.

4.6 Driving Applications of Small Scale Technologies: Applications Development Consortia

There have been many initiatives in Australia over the past two decades directed at the commercialisation of the research activities being undertaken within the universities and public sector research agencies such as CSIRO. Obvious examples include various phases of reform at CSIRO and the Cooperative Research Centre (CRC) Program. Many of these initiatives have played a vital role in strengthening the research base, in both Victoria and Australia, and the CRC Program has played a particularly important role in this regard. But there has still been limited success in strengthening the use of advanced technology by firms or in creating new Australian firms. Our research position continues to be maintained, but we have not built major commercial capability in emerging technologies.

Faced with the massive impact of small scale technologies, this challenge must be addressed head on. In our view, it is time to move from attempting to commercialise research activities to finding ways of having some of the research that is undertaken more directly driven by the commercial imperatives of firms. To this end we propose the establishment of a range of Applications Development Consortia (ADCs). Consortia of various types are widely used in the US and in other countries to facilitate the development of commercial applications of new technologies.

An ADC is a consortium of at least three companies working together to develop and apply small scale technologies in their businesses, in a particular technology or business area. They would come together, with Victorian Government support, to undertake jointly a range of activities R&D, business development and other activities.

Some of the main features of ADCs might be as follows:

- each ADC would be provided with Victorian Government funding of say $3-10 million over five years;
- in general, the companies together would be required to match the Government's contributions on a dollar for dollar basis, through cash or bona fide in kind contributions;
- the funds would be provided to the consortium of companies, and would be used, subject to certain guidelines, purely at the discretion of the companies;
- reflecting this fact, the governance and structure arrangements for the ADC would be simple and straightforward (perhaps a company with equal shareholdings or an unincorporated joint venture), as would be the reporting arrangements to the Government;
- the funds could only be spent on identified activities related to the development and application of small scale technologies;

- while recognising the fact that the ADC needs to draw on skills and technologies from other parts of Australia and internationally, there would be a requirement that 50% of all ADC expenditure be directed to R&D and related organisations in Victoria; and
- rights to any new intellectual property developed through ADC activities would, unless otherwise agreed by the companies, remain jointly and severally with the companies involved, except that R&D institutions would retain rights to the continuing use, for research purposes, of technologies developed in their institution.

The intention of the ADC proposal is to take a further step than that involved in the Commonwealth's Cooperative Research Centres, to provide a direct stimulus to commercially driven development and application of small scale technologies in Victoria. Similarly programs appear to operate successfully in the USA, for example through the National Institute of Health. As well as stimulating the commercial application of these technologies in Victoria, the activities of the ADCs would contribute significantly to increased funding for R&D institutions in Victoria. But this increased funding would be on a strictly commercially driven basis, and one that should eliminate the possibility that the initiative would be 'captured' by the research community.

A competitive process, involving a call for expressions of interest after an extensive national and international process of consultation and publicity, should be used to select ADCs. Eligible companies would include firms owned and operating in Victoria as well as other Australian or international firms operating in, or with a commitment to operating in, Victoria. While recognising the reality that business must, in most cases, seek international application of their technologies if they are to be viable, one of the criteria in the decision process should be the strength and credibility of the company's commitment to develop and apply their technologies in Victoria. A number of ADCs should be reserved for small Victorian-owned companies only, to provide an impetus to company development and alliance formation in the State. Nevertheless, an important aim of this program would be to increase the presence of international firms in Victoria in the area of small scale technologies, and hence to increase the level of foreign direct investment in this area.

4.7 Addressing the Social and Ethical Issues

In Section 2.5 above it was argued that, while many small scale technology developments can proceed without raising serious ethical issues, in the longer term nanotechnology will raise to a new level the social and ethical dilemmas emerging from modern science. Some of these issues are likely to include:

- the environmental and human health issues raised by the increasing use of nanoparticles and the creation of new forms of matter;
- the privacy and security issues arising from vastly increased computing power and from a new wave of defence technologies;
- issues about the nature, identity and preservation of human life arising from new generations of medical technologies based on individual genetic structures;

- questions about the human/machine interface, with increasing capability to incorporate artificial components into human beings and to build 'intelligent' machines; and
- the equity issues, across both individuals and countries, about access to the benefits of small scale technologies.

One central role of Small Scale Technologies Victoria should be to strengthen the capability of the Victorian community to reflect on these issues in a considered and informed manner. It was also argued above that this is not just a matter of increased funding for social and ethical research Rather it will require a broader process of awareness raising and capability strengthening is necessary, including the development of substantial inter-disciplinary research platforms. The new peak body, when established, should give urgent consideration, in conjunction with interested parties and will national and international experts, as to how this might best be achieved.

4.8 Alliances and Networks

It is now well documented that the progress of science is being increasingly driven by collaborations of scientists across institutional, national and disciplinary boundaries. These collaborations take place through informal contacts, networks and formal research alliances. Equally, the commercialisation of that science is being achieved through a rapidly growing number of alliances between companies of different types, and between companies and research groups. It is therefore clear that active participation by Victorian groups in both research and commercialisation alliances will be critical to achieving the objectives outlined above, and that initiatives to facilitate that participation will be an important aspect of policy.

Given its geographical location, participation in international alliances and networks is somewhat more difficult for Victorian firms and researchers than for those located closer to the major intellectual and commercial centres. The major centres of activity will continue to be in North America and Europe, so that alliances and networks with groups in these regions will be most important. Research networks in the USA and Europe are relatively open, so that stronger Victorian links should be possible. The development of commercial alliances remains both most critical and important. But it also an area in which recent Victorian policy has emphasised with some success, so that there is an existing policy framework on which to build.

It was noted above that small scale technologies in general, and nanotechnologies in particular, provide the first case of a major new round of technologies in which a number of Asian countries are participants at the foundational stage. Several advanced East Asian economies – Japan, Korea, Taiwan and Singapore – are already highly expert in various forms of microelectronic technologies, and are making a major investment in nanotechnologies. Other countries, such as China, Malaysia and Thailand, are also undertaking considerable investment is these areas.

The commitment of such a wide range of East Asian countries to small scale technologies provides an important opportunity for Australia and Victoria. Victorian policy should actively promote the development of alliances, networks and other forms of cooperation with research groups and companies in East Asia. There are likely to be many synergies, both in research and in commercialisation, between groups in Victoria and in East Asia. For example, increased value may be generated in some areas by linking Victorian capability in biomedicine with leading edge expertise in Japan or Korea in microelectronics.

4.9 The Institutional Structure: Small Scale Technologies Victoria

The discussion above shows that the initiatives required to achieve the proposed objective – *to make Victoria a leading centre for the commercial development and application of small scale technologies by firms, public agencies and other organisations, in the context of sustained and shared reflection on the social and ethical issues involved* – are complex, diverse and inter-related with one another. They also need to be pursued consistently over a long period of time. As a consequence, there is need for a new peak body – Small Scale Technologies Victoria – to define, coordinate and manage an integrated set of measures to achieve the State's objectives in relation to small scale technologies.

The leadership and coordination role of Small Scale Technologies Victoria will be crucial to achieving the objective proposed here. Various legal structures are available for such a body, and we leave this issue of legal form for further consideration by the Government. Whatever the preferred legal form, four points are crucial about the role of Small Scale Technologies Victoria.

First, it must have a real tripartite presence, with high level and committed leaders from each of industry, the research community and government actively involved.

Second, it must have a long-term focus and role, with the stability of membership, public acceptance and assured funding necessary to pursue its objectives over a decade or more. Third, it must have continuing access to the best available expertise, both from within Australia and from other countries.

Finally, Small Scale Technologies Victoria must have sufficient assured funding to be seen by all parties, both here and abroad, as a serious player in pursuing its objectives, without ever being perceived as yet another granting body. Funding for this new peak body of about $20 million per annum (Table 4), committed for five years in the first instance and renewable subject to review, would be significant in an international context and would provide a strong resource base to achieve the proposed objective. If used wisely, it could also be expected to generate additional funding for particular initiatives, from industry and academia, to an extent which more than doubles the basic government commitment (Table 4).

Table 4. Indicative Budget: Small Scale Technologies Victoria, 2004-2008

Activity	SSTV Expenditure ($ million)	Total Expenditure ($ million)
Demonstration Projects (10 at $4m each)	40	120
Developing the Skills Base	10	30
Applications Development Consortia (5 at $7m each)	35	70
Social and Ethical Capabilities	5	10
Awareness, Alliances and Administration ($2m per year)	10	10
Total	**100**	**240**

4.10 The Next Step

These recommendations are intended as providing the means by which Victoria can become a leading centre for the commercial development and application of small scale technologies. But, especially given the centrality of the *applications* focus, they must be implemented in close consultation with the firms, agencies and other parties whose cooperation will be essential to the outcome. We have already noted that there is limited awareness of the potential role of small scale technologies among Victorian firms and agencies, and indeed among the community at large.

Thus we suggest that the next step should be a detailed and systematic, but not lengthy, process of consultation with key companies, agencies and other groups potentially involved in the development and application of small scale technologies in Victoria. This process of consultation might:

- be undertaken by an Australian group, with the involvement of leading international experts in the area, under the guidance of the Department;
- be based in part on the information and analysis provided in this report, which would be provided to relevant parties prior to the consultation process;
- be directed at identifying, in conjunction with individual firms and agencies, the relevance of small scale technologies to that firm or agency, and the role which those firms and agencies may play in future developments in Victoria; and
- focused also on determining more specifically the infrastructure required to make Victoria a leading centre for the application of small scale technologies, and on assembling the views of different parties on the recommendations in this report.

The detailed document from such a process of consultation would, in our view, provide the final pieces of information needed by the Victorian Government to take fully informed policy decisions to enhance the commercial development and application of small scale technologies in Victoria.

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