# National Collaborative Research Infrastructure Strategy Strategic Roadmap

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# 1 Strategic direction for Australia's research infrastructure

The Government has recognised the need to bring more strategic direction to Australia's investment in research infrastructure. In the 2004-05 Budget, the Government announced that the National Collaborative Research Infrastructure Strategy (NCRIS) would be implemented to provide the greater focus and coordination required.

Funding of $542 million to 2010-11 was allocated to the Strategy in the *Backing Australia's Ability: Building Our Future through Science and Innovation* package.

In October 2004 the Hon Dr Brendan Nelson MP, then Minister for Education, Science and Training, appointed an Advisory Committee, chaired by Professor Rory Hume, to advise on how NCRIS should be implemented. The Advisory Committee submitted its recommendations to the Minister in July 2005 following a public call for submissions and extensive consultations with stakeholders. The Minister accepted the recommendations as the basis for the implementation of NCRIS.

The key principles underpinning NCRIS, reflecting the Advisory Committee's advice, are that:

- Australia's investment in research infrastructure should be planned and developed with the aim of maximising the contributions of the R&D system to economic development, national security, social wellbeing and environmental sustainability;
- Infrastructure resources should be focussed in areas where Australia is, or has the potential to be, world-class (in both discovery and application driven research) and provide international leadership;
- Major infrastructure should be developed on a collaborative, national, non-exclusive basis. Infrastructure funded through NCRIS should serve the research and innovation system broadly, not just the host/funded institutions. Funding and eligibility rules should encourage collaboration and co-investment. It should not be the function of NCRIS to support institutional level (or even small-scale collaborative) infrastructure;
- Access is a critical issue in the drive to optimise Australia's research infrastructure. In terms of NCRIS funding there should be as few barriers as possible to accessing major infrastructure for those undertaking meritorious research;

- Due regard be given to the whole-of-life costs of major infrastructure, with funding available for operational costs where appropriate; and

- The Strategy should seek to enable the fuller participation of Australian researchers in the international research system.

# 2 The role of the Strategic Roadmap

The need to strategically plan investments in research infrastructure has been recognised on a disciplinary basis for some time, with a number of individual research communities developing strategic plans as a guide to potential capabilities.

More recently there has been a move beyond discipline-based strategies to planning on a national (and even multi-national) scale that goes across discipline boundaries. There is international recognition that the support and growth of a strong research and innovation system is reliant upon provision of access to world-class research infrastructure, and that planning for investment in that infrastructure will ensure that the maximum benefits are gained.

The NCRIS Committee, chaired by Dr Mike Sargent, was responsible for the development of the Strategic Roadmap. Further details on the development process can be found at Appendices 1-3.

The purpose of the Strategic Roadmap is to inform decisions on where Australia should make strategic infrastructure investments to further develop its research capacity. It is intended to facilitate a coordinated approach to infrastructure investment across governments and agencies that:

- Concentrates effort nationally on areas of greatest strategic impact;

- Increases collaboration within the research system, and between it and the wider community; and

- Reduces the duplication and sub-optimal use of resources arising from lack of co-ordination.

In developing the Roadmap, the NCRIS Committee has drawn on expert advice and consultation with the research and wider communities. Development proceeded through several steps: consultation on an initial concept; more comprehensive scoping of the options; an expert advisory process; and further consultation on an exposure draft. 192 submissions were received on the exposure draft and considered in drafting this final version.

The Roadmap provides a framework of capabilities*, prioritised on the basis of the NCRIS principles*, that represents the Committee's view as to where medium to large-scale research infrastructure investment should be focused over the next 10 years. It identifies the capabilities that Australia should strive to develop, rather than specific infrastructure, and also make some recommendations on the appropriate means to support them.

**Important note:**

The Roadmap identifies priorities for investment in research infrastructure, based on the NCRIS principles. It is not a general statement of research priorities.

More specifically, the Roadmap will provide a framework for the allocation of the NCRIS programme funding available from 2006-07 onwards. It is the Government's intention that the Roadmap should be an evolving planning tool that is updated periodically to reflect changing priorities and the emergence of new opportunities.

# 3 Prioritisation of capabilities

The process of developing the Roadmap has made it clear that the potential exists for Australia to further develop a wide range of research capabilities to a level that would be competitive in the international context.

Consistent with the NCRIS principles, the Roadmap identifies those capabilities that will provide the most strategic impact in terms of delivering national benefit, producing world-class excellence in both discovery and application driven research, and/or enhancing the overall capacity of the research and innovation system by providing enabling research platforms and promoting accessibility and collaboration.

The Roadmap comprises an integrated set of capabilities that ensure critical linkages are maintained and that a value-adding chain of research and innovation activities is enabled in key areas.

The scope of the priority capabilities recommended in the Roadmap has been necessarily constrained by the level of funding that might realistically be available through the NCRIS programme and from co-investment by other parties. The size of individual NCRIS funding investments has therefore been limited to an upper limit of approximately $60 million per capability. Capabilities likely to require funding above that level are considered 'landmark infrastructure' (see below).

## 3.1 Landmark infrastructure

'Landmark infrastructure' (i.e. requiring funding of greater than approximately $60 million) is outside the scope of the Strategic Roadmap and the NCRIS funding process. While the NCRIS Committee did not seek to systematically scope or analyse the need for landmark infrastructure, a number of potential landmark infrastructure projects emerged. Examples include a blue-water research vessel capability, Australian investment in next generation optical and radio astronomical instruments, and Australian participation in the International Thermonuclear Experimental Reactor (ITER) consortium.

It is not within the scope of the NCRIS Programme to provide a means whereby proposals for large-scale infrastructure proposals can be developed or considered by government.

# 4 Implementing the Strategic Roadmap

The Government's aim is to provide support for each of the capabilities identified in the Roadmap. However the extent to which that is possible will depend on the overall resources available to fund the Strategy from both the NCRIS programme and co-investment or in-kind contributions from other parties.

An *NCRIS Investment Framework* will be produced to describe the investment proposal process in detail and to specify the investment criteria that proposals must meet. To achieve an effective roll-out of the Strategy, the Roadmap will be implemented in three phases.

1 The Government will focus initially on implementing nine high priority areas of capability (see 4.1: "Proposals to be developed in 2006"). These have been judged to be high priority in terms of strategic impact and their potential to be 'investment-ready' within six to nine months.

   i) Beginning in February/March 2006, the NCRIS Committee will work intensively with the research community, State and Territory Governments and research organisations, through designated facilitators or coordinating bodies, to develop a suitable investment proposal and business plan for each of these capabilities. Funding will be available to support proposal development costs, including support for facilitators.

   ii) The aim will be to have investment proposals which meet the NCRIS investment criteria ready for approval by the Minister by September 2006[1].

2 A further group of two high priority capabilities will require scoping or analysis to take place within the research community before it would be feasible to develop a full investment proposal (see Capabilities requiring development work before proceeding to full implementation proposals).

   i) A modest amount of funding will be provided to help facilitate scoping and networking activities leading up to the development of a full investment proposal commencing later in 2006 or early in 2007. The NCRIS Committee will consult with relevant sections of the research community in early 2006 to identify the best means to progress this work.

   ii) Development of full investment proposals for these capabilities could begin as soon as the issues and options have been adequately scoped.

3 A third group of capabilities will be reviewed for possible implementation in 2007 (see Proposals to be considered in 2007).

[1] Throughout the Roadmap references to a September 2006 'deadline' are indicative only. Proposals that can be developed and brought forward earlier will be considered when ready.

## 4.1 Proposals to be developed in 2006

- Evolving biomolecular platforms and informatics
- Integrated biological systems
- Characterisation
- Fabrication
- Biotechnology products
- Networked biosecurity framework
- Optical and radio astronomy
- Integrated marine observing system
- Structure and evolution of the Australian continent

## 4.2 Capabilities requiring development work before proceeding to full implementation proposals

- Population health and clinical data linkage
- Terrestrial ecosystem research network

## 4.3 Proposals to be considered in 2007

- Translating health discovery into clinical application
- Heavy ion accelerators
- Low-emission, large-scale energy processes
- Next generation solutions to counter terrorism and crime

## 4.4 Platforms for collaboration

The Government will continue to support the development of the underpinning technological platforms that enable the research community to efficiently collect, share, analyse, store and retrieve information.

## 4.5 Development of proposals

The Government intends that a single national, collaborative proposal (incorporating a business plan) be developed to address each area of capability.

Development of each proposal will be undertaken through a designated facilitator or coordinating body, external to DEST, reporting to the NCRIS Committee. Facilitators will be identified in consultation with the states and territories, research community and relevant organisations to ensure broad support and acceptance. In some cases an appropriate coordinating organisation has already been identified in the Roadmap.

It will be the responsibility of the facilitator to liaise with stakeholders to identify infrastructure requirements in detail and to develop a plan for addressing those needs, covering issues such as:

- the strategic prioritisation of components identified in the Roadmap;
- the role of existing facilities and infrastructure;
- financing of the proposal (in the context of whole-of-life costs) from both NCRIS programme funds and co-investments from the interested parties;
- access issues and charging regimes;
- management and governance structure; and
- coordination of investment planning across proposals to ensure the best use of available funds.

The information and advice provided in submissions on the exposure draft will be an important and valuable resource and starting point for this process.

The Government will expect there to be broad support and acceptance by the community that the proposal provides the best way forward for each capability. An NCRIS grant will be provided to assist in the development of proposals. The grant will be available to contribute to the salary of the facilitator and other expenses related to the development of proposals.

Stakeholders should take particular note of the NCRIS principles, which require that NCRIS funded projects will support the development of national capabilities that:

- Substantially enhance collaboration across Australia, internationally, between disciplines and across research sectors;
- Focus on the delivery of services to the research sector and the maintenance of world-class technological capability;
- Generally enable excellence in research and the development of world-class niches and international leadership in key areas;
- Have a clearly defined and appropriate management structure;
- Do not lead to further duplication of research infrastructure; and
- Are broadly accessible on the basis of merit.

**Important Note**

Readers should note that this document is **not a call for proposals** for NCRIS funding. The Roadmap will be implemented in a staged sequence through a facilitated proposal development process as outlined above.

# 5 Overview of priority capability areas

This section describes the priority capabilities identified by the NCRIS Committee and provides its recommendations relating to each capability.

**Summary of priority capability areas:**

(Note: the numbering of capabilities does not reflect any order of priority)

- 5.1 Evolving bio-molecular platforms and informatics
- 5.2 Integrated biological systems
- 5.2.1 Animal models of disease
- 5.2.2 Plant phenomics
- 5.2.3 Biological collections
- 5.3 Characterisation
- 5.3.1 Neutron scattering
- 5.3.2 X-ray techniques
- 5.3.3 Optical and electron microscopy/microanalysis
- 5.4 Fabrication
- 5.4.1 Fabrication of advanced materials (including nano-materials)
- 5.4.2 Bio- and chemo- pre-commercial synthesis, fabrication and rapid prototyping
- 5.4.3 Micro/nanofabrication enabling microelectronics, photonics, optoelectronics, integrated optics
- 5.5 Biotechnology products
- 5.6 Translating health discovery to clinical application
- 5.7 Population health and clinical data linkage
- 5.8 Networked biosecurity framework
- 5.9 Heavy ion accelerators

- 5.10 Optical and radio astronomy
- 5.11 Terrestrial ecosystem research network
- 5.12 Integrated marine observing system
- 5.13 Structure and evolution of the Australian continent
- 5.14 Low-emission, large-scale energy processes
- 5.15 Next generation solutions to counter crime and terrorism
- 5.16 Platforms for collaboration
- 5.16.1 Data access and discovery, storage and management
- 5.16.2 Grid enabled technologies and infrastructure
- 5.16.3 Technical expertise
- 5.16.4 High performance computing
- 5.16.5 High capacity communications networks

## 5.1 Evolving bio-molecular platforms and informatics

### 5.1.1 Description

The last decade has seen rapid and continuing advances in technologies supporting analysis of the molecular basis of biological systems. These technologies are enabling vast amounts of information to be generated, and are promoting the emergence of new areas of research within the biological sciences.

The technologies and their associated areas of research focus on different (but related) areas, relating respectively to:

- Gene discovery and genome analysis (*genomics*);
- The structure and function of primary gene products (*proteomics*);
- The analysis of metabolites in particular cells, tissues, fluids, organs or organisms at a given point in time (*metabolomics*); and
- How genes are expressed in differing contexts (such as in different tissues, populations and species) as well as through time (*transcriptomics*).

The volume of information being produced creates major information management challenges. Technologies and an area of research focus have emerged to address these challenges (*bioinformatics*).

### 5.1.2 Rationale

Research in these fields is producing a continuing stream of advances in our understanding of the structure and function of living systems. Over 300 genomes have now been sequenced. Together with advances in genetics, high-throughput biochemistry and bioinformatics, this research effort has created a comprehensive and rapidly growing pool of knowledge and resources. However, this revolution in the biological sciences is just beginning.

The potential benefits flowing from research in these areas are enormous and include:

- The discovery and development of drugs, including new-generation genetically based treatments;
- The development of novel functional foods with enhanced nutritional/fibre/nutriceutical value now recognised to play a crucial role in promoting a better quality of life and longer life expectancy;
- The development of novel crop varieties with enhanced capacity to withstand stresses such as salinity, drought, frost, mineral deficiencies and toxicities and pathogens/pests;
- The development of crops with reduced dependency on fertilisers, promoting both the environmental sustainability and competitiveness of Australian agriculture; and
- Improved bio-security through the rapid detection and characterisation of threatening human pathogens (e.g. avian flu) and agricultural pests.

Opportunities to link the explosion of emerging information with other large data collections are also emerging. Clinical data sets relating to (for example) cohorts, populations, clinical research, tissue banks and clinical trials have the capacity, through linkage to the evolving bio-molecular information base, to build an understanding of the complex origins and development of important diseases. Similarly, there is an opportunity to further develop and create linkages with taxonomic datasets in order to fully realise the potential benefits relating to the sustainable use of our natural biodiversity (e.g. natural product discovery).

Australia has maintained an internationally competitive position in several of the platform technologies needed to support research in these areas. These platforms are stimulating and transforming fields such as cellular biology, botany, zoology, ecology, microbiology, biochemistry and genetics, while drawing disciplines such as chemistry, informatics, physics and mathematics into collaborative research efforts and approaches. However, the rapid pace of progress within these technologies creates a requirement for the development and maintenance of a capability that is at the forefront internationally, with respect to both development and use.

## 5.1.3 Infrastructure/support requirements

A number of possible areas for investment have been identified, relating to infrastructure within Australia and to participation in international research efforts.

### 5.1.3.1 Infrastructure

There is a need to both address current gaps in capability and to better build on the many existing centres across Australia, coordinating them into national, collaborative efforts and supporting their engagement with industry. Specific areas for investment might include:

- High throughput biomolecular analysis platforms in areas of both existing strength and current gap. Specific platforms might include: genomics, proteomics, transcriptomics, and /or metabolomics;
- Crystallography, nuclear magnetic resonance and mass spectrometry facilities supporting analysis of biological structures and the modelling/prediction of their behaviour;
- Microscopy, spectroscopy, access to cell imaging etc;
- Generic e-science tools and solutions under (5.16) supporting bioinformatics efforts.

### 5.1.3.2 Participation in International Networks and Programmes

Australia needs to participate in relevant international bionetworks and programmes in order to stay abreast of developments in these fields.

The Committee recommends that close consideration be given to Australian participation in the European Molecular Biology Organisation (EMBO) and the European Molecular Biology Laboratory (EMBL). Such participation would provide Australian researchers across the life sciences with access to levels of resources, technology and critical mass unavailable in Australia, together with research training placing our young researchers at the cutting edge of their fields and promoting the diffusion of research knowledge into its areas of application in industry and elsewhere.

## 5.1.4 NCRIS Committee recommendations

The NCRIS Committee recommends that work commence as soon as possible, through an appropriate facilitator, to bring forward a coordinated proposal by

September 2006 to further develop Australia's biomolecular platforms and informatics capability.

Responses to the Exposure Draft of the Roadmap indicated broad support for the infrastructure requirements identified above and a strong preference for structuring capabilities in a distributed network that provides geographically spread capabilities with broad application (rather than a discipline or outcome specific focus), as well as the need for improved accessibility regimes and industry linkages. The proposal should present an approach that is consistent with that feedback.

Responses to the Exposure Draft also indicated strong support for a subscription to EMBO/EMBL. The Committee recommends that the proposal specifically include presentation of a business case for Australian participation in EMBO/EMBL. It would expect that provision for Australia's participation in other relevant international programmes would be evaluated in the course of the proposal development.

The proposal should stipulate how effective integration and coordination of existing and any proposed new platforms and technologies (including those within other capabilities in the Roadmap) would be achieved and what role an enhanced bioinformatics capability might play in supporting this integration (including "whole-of-system" approaches that might develop from it).

## 5.2 Integrated biological systems

Understanding biological systems requires not only an understanding of their constituent elements and sub-systems, but also of how these interact with each other and with the wider environment. These interactions are attracting increasing attention in a number of areas of biological research.

To support this research, capabilities are required that: enable the generation and maintenance of genomic resources; provide the capacity to identify the functions of particular genes; and provide a broad range of suitable "model systems" that can be studied to improve our understanding of more complex organisms and processes. For example, microbes provide excellent models for the development of methodologies that can then be applied to more complex life forms and plant and animal models are useful in elucidating disease, growth and development in humans, livestock (including aquaculture) and crops.

This capability is integrally linked to 5.1 and has relevance to establishing the preclinical pharmacodynamics and efficacy of new therapeutics (5.6); and clinical and population studies in humans and livestock (5.6 and 5.7). Areas for infrastructure investment have been specifically identified in relation to animal models, plant phenomics and biological collections. E-science tools will be critical in enabling broad access in these areas and integration with other capabilities.

### 5.2.1 Animal models of disease

#### 5.2.1.1 Description

Progress in understanding and treating disease can be significantly enhanced by the development of appropriate animal models in which the course of a disease and effects of treatment can be tested.

#### 5.2.1.2 Rationale

Australia invests significantly in research to understand and utilise animal models of human disease. A recent example of world class Australian research in animal disease models is the development of the world's first animal model of human epilepsy. A number of animal genetic diseases have also been discovered which have human analogues and are mediated by the same genes and biochemical pathways. In addition, Australia's world class investments in animal sciences underpin its significant multibillion dollar livestock industries, through powerful integrated quantitative and molecular genetics, as well as phenotypic research on impacts of nutrition, management systems and different environment on animal production and health.

The past 10 years has seen revolutionary advances in gene targeting and stem cell technologies, cell and tissue storage, animal phenotyping and xenotransplantation. Concurrently, there have been advances in medical imaging techniques which provide non-invasive and direct insights into normal and abnormal systems biology. Multimodal imaging has emerged as an important enabling platform. There is an opportunity to build a national integrated capability in Australia which captures these advances and facilitates development of novel animal models of mammalian development, growth and diseases, including access to phenotyping and imaging facilities at a level comparable to those available to international researchers.

Such a capability would help build on Australia's strengths in neuroscience, cardiology, respiratory and renal medicine, oncology, perinatology, endocrinology, metabolic and degenerative diseases and surgery, while enabling researchers to move more rapidly from research outcomes to the development of therapeutic approaches.

#### 5.2.1.3 Infrastructure/support requirements

Key components contributing to an integrated capability supporting animal development, growth and disease models include:

- Gene targeting technologies;
- Cell and tissue storage;
- Archiving and distribution of mutant strains;

- Animal phenotyping facilities;
- Specialist animal holding, breeding and surgical facilities, in association with
- Imaging capability for small and large animals, and
- Application and development of new bioimaging technologies.

Recommended areas for investment include:

- The development of a centralised mouse phenotyping facility, together with linkages between centres working with genetically altered mouse models with those working with advanced disease models;
- Support for advanced imaging facilities, relevant to a range of animal models of development, growth and disease, structured in a way which would promote and enhance co-ordination between existing facilities, promote systematic transfer of knowledge across disciplines, disease and national boundaries and provide a focus for the continued development of imaging techniques; and
- The development of stronger linkages between centres dealing with human health and disease and those with expertise in animal models.
- Participation in the International Neuroinformatics Coordinating Facility (INCF), an international project aiming to coordinate international efforts to manage the vast, complex and rapidly escalating quantities of data generated in neuroscience. Participation would build on, and integrate, the outcomes of existing research efforts in neuroscience across Australia, including the National Neuroscience Facility (MNRF) and related technology (e.g. imaging, phenotyping etc) and clinical capabilities (e.g. neuroscience clinical trials).

Other potential areas for investment include: a mutant animal archive; animal oncology and reproductive facilities; an Australian node of international mouse knockout library efforts; animal phenotyping facilities linked to expertise in development, growth and disease modelling; frozen mouse embryo storage facilities; xenotransplantation facilities; specialist small and large animal breeding, holding and surgical facilities; a large animal imaging facility; and accessible, integrated databases supporting animal models of disease, preclinical research and development capabilities and genetic improvement of livestock.

Provision of appropriate support would facilitate Australian linkages with, and participation in, international efforts such as the European Mouse Mutant Archive and the NIH's stem cell mouse genome initiative, and would better assist our researchers to produce and contribute to world class outcomes in model animal research and related research focus areas.

## 5.2.2 Plant phenomics

### 5.2.2.1 Description

The major challenge facing the plant science community, locally and internationally, is to develop improved capabilities to accurately "phenotype" mutant or new plant varieties. To date, a major focus in botanical/agricultural systems has been genome sequencing and the study of how genes are expressed. The challenge is to obtain an integrated picture of plant performance, under controlled conditions, throughout the plant lifecycle.

### 5.2.2.2 Rationale

While Australia has traditionally excelled in molecular biology and plant physiology, no concerted effort has yet been made to bring together nodes of expertise in these fields to address plant phenomics.

Australian agriculture would benefit significantly from enhanced capability in plant phenomics through the development of techniques to improve both the yield and quality of crops through minimising the effects of environmental and biological (pathogens/pests) stresses, and a reduced dependence on pesticides, fungicides, herbicides and fertilisers. There is considerable distributed but unconnected capability around the country in a range of plant breeding and production programs, industries and environments and appropriate linkages with these to explore genotype by environment interactions will be important.

### 5.2.2.3 Infrastructure/support requirements

Existing facilities within Australia have varying infrastructure dedicated to the growth of experimental plants within conventional glasshouses and/or plant growth cabinets. There are nodes of expertise in the non-invasive analysis of plant performance, such as optical, hyperspectral and chlorophyll fluorescence imaging, focussed on individual plant species
and/ or small scale research projects which include laboratory and field-based research.

The infrastructure gap is in bringing these two key areas together (controlled plant growth conditions and cutting edge plant performance monitoring) in a national plant phenomics facility. This would be most effectively achieved by creating a central focus for these activities feeding out through interaction with this centre and networking into the significant advances being made in remote sensing to support precision management of the rice, cotton, grains, pastures and forestry industries.

## 5.2.3 Biological collections

### 5.2.3.1 Description

A number of animal, plant, invertebrate and microbe collections exist across Australia. In addition to supporting essential taxonomic, systematic and biogeographic research, these collections provide an important capability for research in areas such as evolutionary biology, biodiversity, models of disease, resource management, and biosecurity.

#### 5.2.3.2 Rationale

Biological collections provide an important supporting infrastructure for research relating to models of disease, biosecurity and biodiversity, as well as supporting quarantine, environmental remediation and management. For example, microbes and invertebrates such as insects can be used as bio-indicators, while genetically modified bacteria have the potential to contribute to the treatment of waste-water and toxic wastes.

Wide access to unique libraries such as mouse collections is currently limited by the lead-time and up-front cost to produce this infrastructure, and by the need to integrate these biological collections with technologies to capture widely useful phenome data coupled with genotype data. Assembly of national collaborative phenome libraries would enable access within the time and budget constraints of research project grants, enabling a wide range of researchers with expertise in specific organ systems to discover new mechanisms and integrative animal models.

There are also immediate opportunities to multiply the deliverables from these libraries by attracting international investment for value-adding projects in specific disease areas.

#### 5.2.3.3 Infrastructure/support requirements

There is an opportunity to more fully digitise and link existing collections and thereby leverage more value from them. Full databasing and linkage of existing collections, along with provision of associated informatics capabilities, would be desirable and enable better utilisation of genomic resources in this area. Linking molecular capability to physical collections in targeted areas will be critical for this.

Opportunities to participate in international activities that would allow more rapid and reliable identification, especially for currently difficult-to-identify taxa also warrant consideration. Examples are: Australia’s membership of the Global Biodiversity Information Facility (GBIF), a megascience facility with the aim of making the world’s primary data on biodiversity freely and universally available in standard formats via the internet; and the Consortium of the BarCode of Life (COBOL), which aims to accelerate the classification of the world’s invertebrates, plants and micro-organisms by sequencing the same specified genome segments across a huge range of organisms.

It is recommended that the investment focus be on infrastructure and expertise to leverage unique national collaborative libraries of multiplexed missense mouse variants, Arabidopsis, key crop variants, biodiversity collections and international collections of gene-targetted ES cells.

#### 5.2.3.4 NCRIS Committee recommendations:

The NCRIS Committee recommends that work commence as soon as possible, through an appropriate facilitator, to bring forward a coordinated proposal by September 2006 to further develop an integrated biological systems capability.

Potential priority areas for the proposal include:

- Development of a national mouse phenotyping facility (as well as associated linkages between centres which have a capability in genetically altered mouse models and those working with advanced disease models and further, between animal modelling centres and clinical research centres);
- A national framework to enable non-invasive imaging of small and large animal models and support for the development and knowledge transfer of new imaging techniques relevant to a range of animal models of development, growth and disease;
- Development of a national distributed facility dedicated to the phenomic analysis of plant performance that brings together capabilities in controlled plant growth conditions and cutting edge plant performance monitoring;
- Databasing and linkage of existing animal, plant, invertebrate and microbial collections, along with provision of associated informatics capabilities;
- Support for Australia’s participation in the INCF. The Committee recommends that provision for Australia’s participation in other international programmes such as GBIF and COBOL be evaluated as part of the proposal development.

The proposal should demonstrate that there has been adequate consideration of how the various components of the capability fit together and integrate with other capabilities.

## 5.3 Characterisation

One of the fundamental requirements of researchers in the physical sciences, life sciences and engineering is for equipment that enables them to characterise the physical, chemical and structural attributes of matter (both non-living and living) and determine how those attributes change over time (for example, if subjected to external stresses). There are a wide range of techniques used, including:

- Optical and electron microscopy and spectroscopy;

- Scanning probe techniques, including atom, ion and optical probes;
- X-ray diffraction, spectroscopy and imaging;
- Neutron scattering;
- Magnetic resonance imaging and spectroscopy;
- Time of flight mass spectroscopy; and
- RAMAN and infrared spectroscopy.

While some characterisation work can be performed on relatively inexpensive laboratory equipment, a number of key techniques are expensive, require specialised skills and are best operated as central facilities open to all researchers.

Neutron scattering, x-ray techniques and high-level microscopy and microanalysis fall into this latter category. Each has been identified as needing additional investment to deliver the suite of characterisation capabilities required to underpin world-class Australian research in the physical sciences, life sciences and engineering.

## 5.3.1 Characterisation – neutron scattering

### 5.3.1.1 Description

Because neutrons can non-destructively penetrate deeply into materials, researchers can use them to obtain information on the properties of both organic and non-organic materials. Neutron scattering involves firing a beam of neutrons at a sample and making inferences about the nature of the material based on how the neutrons scatter after contacting the sample.

Neutron scattering finds particular application in the study of “soft-matter” materials such as polymers, complex fluids and those comprising biological systems, as well as in magnetic and electronic materials. It provides different but complementary information to that obtainable using other characterisation techniques. In biological applications, for example, while x-rays offer high temporal and spatial resolution of a structure, neutrons offer contrast variation for selective investigation of the component parts of a large biological complex. For this reason neutron scattering is increasingly regarded as an important tool in the range of techniques available for structural biology. At the other end of the scale, neutrons can easily travel through centimetres of solid steel, making them ideal for studying stresses in engineering components and for applications in materials science in general.

### 5.3.1.2 Rationale

Australia has a long and distinguished track record in neutron science dating back to 1958. It now possesses a world-class neutron scattering capability in the recently commissioned Open Pool Australian Light-water (OPAL) reactor at ANSTO, which will be one of the top three research-reactor centres in the world for neutron scattering techniques. When fully operational in 2006, this facility is likely to raise Australia's capability in neutron science to the highest international level while increasing competitiveness in other key areas such as nanotechnology and attracting leading international research teams to Australia.

Knowledge derived from neutron scattering has a wide range of applications in the manufacturing, minerals, agriculture and pharmaceuticals industries. It addresses many of the Priority Goals identified in Australia's National Research Priorities. To take one example, relating to the goal of *reducing and capturing emissions in transport and energy generation*, neutron scattering has been used to build knowledge about how hydrogen (a promising alternative fuel) might be stored and used efficiently to generate electricity[2].

#### 5.3.1.3 Infrastructure/support requirements

The new OPAL neutron source, with an initial suite of nine instruments each providing a different method and scientific/technological focus, will come on line in 2006. A survey of likely demand conducted in April 2005, showed that half of the initial suite of instruments will be oversubscribed from the outset, and that some of its capabilities will need to be duplicated soon after OPAL starts operating. It is anticipated that OPAL's usage will double over the first few years of operation. Growth could be even more rapid if investments are made in extra beamlines and additional guides (up to nine extra beamlines, for example, could be accommodated by OPAL to further enhance its capacity and functionality).

The most immediate priority, however, is the provision of a deuteration[3] facility for either low or high molecular weight compounds. The ability to deuterate samples has long been a key issue for biological and organic molecular neutron scattering. Tools and facilities are required for the specific and selective isotopic-labelling of complex bio-molecules (eg proteins, nucleic acids and lipids), synthetic macromolecules, amphiphiles (eg surfactants) and small organic molecules (eg. drugs). The provision of these deuterated molecules should greatly enhance both the quality and quantity of neutron experiments that can be undertaken at OPAL. In addition these deuteration facilities would enable more sophisticated NMR experiments, which will be important, for example, to the proteomics community. The lack of such a facility will be a major limitation for soft matter research.

### 5.3.2 Characterisation – X-ray techniques

#### 5.3.2.1 Description

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[2] For example, studies using neutron scattering have characterised the hydrogen adsorption capacity of carbon nanotubes and aspects of the operation of membranes used in polymer electrolyte fuel cells.
[3] Deuteration introduces "heavy water" into a sample to improve the quality of neutron scattering data.

X-ray techniques are central to the characterisation of both hard and soft matter, and are widely employed on the laboratory scale. They enable determination of structures, chemical composition and imaging in both two- and three-dimensions of complete samples, and can image both engineering components and biological systems.

X-rays provide information on the crystallographic and molecular structure of materials that is different from, but complementary to, the information obtainable from neutron scattering. While many x-ray techniques can be performed in the laboratory, the major advance in x-ray techniques has been the advent of synchrotrons, which produce beams of very intense electromagnetic radiation covering a major part of the spectrum, from far infrared light to hard x-rays. In third generation machines, the intensity obtainable will be up to $10^9$ times greater than the intensity from a conventional laboratory source. This enables very short exposure times, and the possibility to do time dependent studies of chemical and physical processes.

#### 5.3.2.2 Rationale

Synchrotron techniques are increasingly important in a broad range of biological, health, physical science and engineering disciplines. In relation to industrial research, there are growing applications in the minerals, agriculture and food processing sectors, for drug discovery, development and production.

They are also important for environmental research programs. For example, spectrographic beamlines enable the measurement of very small concentrations of toxic materials in soils, streams, seawater or the atmosphere. In this context, they have been used to investigate the uptake of heavy elements by plants and micro-organisms in order to develop mine and industrial site remediation strategies.

The ability to access world-class synchrotron techniques will address a current substantial unmet need for synchrotron techniques among Australian scientists that is limiting their ability to perform cutting-edge research in a broad range of fields. New tele-presence capabilities (as for example will be supported on the Australian synchrotron), moreover, are likely to greatly facilitate and encourage collaborative efforts amongst researchers both within Australian and with research groups internationally.

#### 5.3.2.3 Infrastructure/support requirements

Australian researchers have been accessing synchrotrons overseas through DEST’s Australian Synchrotron Research Programme and Access to Major Research Facilities Programme. However, the acquisition of a domestic, world-leading capability has become essential. There is currently substantial unmet need for synchrotron techniques among Australian scientists that is inhibiting their ability to perform world class research. There are major logistical limitations and cost penalties involved in accessing overseas synchrotrons, particularly affecting life sciences and time critical industrial applications. Moreover, data gathered at some overseas synchrotrons can be subject to intellectual property ownership restrictions. These problems make it difficult for researchers to support industry requirements, which usually require rapid response, and impact particularly on students and early career researchers.

**Australian Synchrotron**

The Australian Synchrotron is under construction and will come on stream in 2007. It will be a third generation machine designed for optimum performance in the x-ray range. It is expected that over 1,200 people nationwide will use the facility each year. When operational it will provide a world leading capability in a number of areas.

The Victorian Government is funding the construction of the buildings and main machine. A consortium of universities, CSIRO, ANSTO, medical research institutes (AAMRI), state governments and New Zealand have so far committed in-principle funding toward the cost of an initial suite of 9 beamlines. These will perform a range of techniques expected to be able to meet 95% of the anticipated needs of the Australian and New Zealand scientific and industrial research community for synchrotron techniques. Further beamline developments and the use of tele-presence are also planned. This will be achieved through coupling with the AARNet and the Australian Government’s e-research initiative.

The initial beamline suite (and subsequent beamlines) requires additional capital funding to become operational. However, prior to any commitment of NCRIS funding it is critical that issues related to the operating budget of the facility are resolved satisfactorily.

**Access to International facilities**

Provision of continued support for the access of Australian researchers to international synchrotron facilities will be important to cover the Australian Synchrotron phase-in period and access to capacity that will not be available when it becomes fully operational.

## 5.3.3 Characterisation – high-level microscopy and microanalysis

### 5.3.3.1 Description

Optical, scanning probe and electron microscopes, along with other microscopy and microanalysis techniques, permit characterisation of matter on a fine scale. Optical microscopy provides imaging of surfaces, thin sections and dispersions of particles down to the micron scale. Over the past few years, several techniques have increased the level of resolution that is achievable and opened the possibility of optically characterising biological specimens, including live cells. *Scanning probe* *microscopy* covers several related technologies for imaging and measuring surfaces down to the level of molecules and groups of atoms. Electron microscopy has been steadily evolving over the past 40 years, with the most recent transmission electron microscopes (used for characterising advanced materials as well as biological tissue) able to resolve structures at the atomic level, below 0.1nm.

#### 5.3.3.2 Rationale

Optical, scanning probe and electron microscopy enable a wide range of research. A number of centres around Australia, mostly within universities, are equipped with at least some of these facilities. While in many cases this equipment is modern and of a high standard, a significant proportion is quite old, expensive to maintain and has limited capability. Those who run these facilities often report the equipment is under-utilised because of lack of staff and funding to support a wider program. In some cases the particular research focus of the host institution has narrowed the range of applications as well.

Well-run centres equipped with advanced instruments and skilled staff would facilitate excellent research as well as providing a clearing house for the latest ideas because of the wide range of activities undertaken and the drive and resources to develop the techniques to their full extent. Interaction between the staff and other researchers using the centre would stimulate collaboration.

#### 5.3.3.3 Infrastructure/support requirements

The Committee suggests that the most suitable means of supporting a strong Australian capability in high-level microscopy and microanalysis would be through the provision of a network of optical, scanning probe and electron microscopy and microanalysis facilities, with:

- Nodes in each major capital city (with formal links to smaller units operating in institutions and or specialist facilities);
- A full, modern suite of instruments, building on existing investments, together with sufficient skilled staff to ensure that the potential of the techniques is fully realised and the facilities operate at a high level of productivity;
- Electronic linking of the centres, together with central, long-term archiving, in a common format, of images and experimental data produced by them. (The storage format will need to be designed so that images of the same sample made by different techniques (including x-ray and infra-red imaging at the Australian Synchrotron) can be compared and superimposed.) Key pieces of equipment should ideally be equipped with a tele-presence capability so that particular capabilities that one centre may have developed can be made available nationally.

- Access available to all researchers, irrespective of their institution, based on the scientific excellence of their work. It will be critical to ensure that centres truly service their region and are not ‘captured’ by their host institution.

It would be highly desirable also to link the centres to a nationally networked database and capability for interpreting structural data at the nanoscale.

#### 5.3.3.4 NCRIS Committee recommendations

The NCRIS Committee recommends that work commence as soon as possible, through an appropriate facilitator, to bring forward a coordinated proposal by September 2006 to further develop Australia’s characterisation capability.

Strong support was received in response to the Exposure Draft for all three capability areas above and the Committee would expect the proposal to specifically address those elements.

Furthermore it is the Committee’s view that these areas are highly complementary and would benefit from better coordination and integration with each other and with other capabilities outlined in the Roadmap (particularly 5.4 Fabrication).

The Committee is aware from responses to the Exposure Draft that some early discussions towards improving coordination and integration of national characterisation capabilities have taken place.

## 5.4 Fabrication

Australia needs a capacity to produce industrial trial quantities of materials, fabricate product components, rapidly produce prototypes for testing, and package devices in order to help provide paths to market for world-class Australian research.

Three important areas have been identified as having capability gaps that could be addressed through NCRIS funding. These are: advanced materials (including nanomaterials), bio- and chemo-based products, and microelectronics, photonics, optoelectronics and integrated optics.

### 5.4.1 Fabrication of advanced materials (including nano-materials)

#### 5.4.1.1 Description

Advanced materials are fundamentally important to all modern technologies from aerospace, automotive to biomedical devices, with potential to address a wide range of the goals identified in Australia’s National Research Priorities. For example, in relation to the goal of *reducing and capturing emissions in transport and energy generation*, nanomaterials are playing an important role in efforts to increase the efficiency of photovoltaic cells, as well as in efforts to lower the prospective cost of hydrogen-driven transportation by reducing the amount of platinum needed in Proton Exchange Membrane Fuel Cells.

One of the hallmarks of advanced materials – whether they be polymeric, metallic, organic or inorganic in nature - is the rational design and controllable processing of their building blocks. Increasingly the building blocks for advanced materials with novel and/or improved properties are found in the nanosized range. It is widely recognised that building blocks at the nanoscale such as nanoparticles, nanotubes and nanofibres often hold the key to materials' properties and performance. These building blocks can be produced in several ways: by "top down" approaches e.g. grinding, atomisation or electrospraying, or by "bottom up" approaches from the atomic or molecular constituents, e.g. crystallisation, colloidal precipitation, or growth from a gaseous deposition.

These precursor materials or building blocks can be useful products themselves, but often need to be built into engineered products or devices using processes such as powder compaction, sintering, spin coating, spray coating, extrusion, and other forming techniques.

#### 5.4.1.2 Rationale

A number of Australian research centres are producing world class research in the area of 'advanced materials'. There is good capability to synthesise and test materials in the laboratory, but generally only small quantities (often only grams) can be produced at a time. In contrast, research organisations overseas can access facilities enabling them to make and characterise kilograms of materials. This gives them the ability to test advanced materials and their production processes on a pre-pilot scale, which is crucial for fully testing their properties and performance and for convincing potential users or investors to support scale-up production or pilot trials. Such scale-up and prototype facilities are not available in any Australian research organisation, and are needed to enable research in advanced materials to move from the laboratory bench into useful applications.

#### 5.4.1.3 Infrastructure/support requirements

This capability could be supported by the establishment of one or two national advanced materials prototyping and small scale production facilities to enable the manufacture of advanced materials at a scale of several kilograms.

Several commercial ventures have been spun out of research centres in Australia for production of nanopowders. These enterprises specialise in specific technologies and families of powders so could not be expected to provide a broad service to researchers. However it is possible that these facilities could provide the basis for establishing one or two scale-up centres linked to the key research centres in advanced materials and nanomaterials.

A possible investment strategy might be to have two centres of scale up facilities established in Australia, each specialising in a focused area. For example, one centre could have a focus in soft materials including polymeric, organosilicate, and nanocomposites and biomaterials, and another in hard materials including inorganic particles, thin films and coatings, and consolidated materials sintered from powders. The type of equipment, processing units and tools, as well as advanced materials performance testing facilities required would include: heaters and autoclaves for sol gel and hydrothermal processing, powder compaction, sintering furnaces, electrospraying, spin coaters and dip coaters, air spraying, catalytic vapour deposition reactors and flame particle synthesis reactors. Specialised equipment for soft materials such as polymer nanoparticles such as layer-by-layer processing, and self-assembled amphiphile colloidal particles at a larger scale than a few hundred grams would also be desirable.

### 5.4.2 Bio- and Chemo- Pre-Commercial Synthesis, Fabrication and Rapid Prototyping

#### 5.4.2.1 Description

Australia maintains a significant research effort devoted to an area that can loosely be described as biomaterials research. This area includes bulk biomaterials, and surfaces and systems that are either biomimetic, bioresponsive, biocompatible or bioregenerative, including the promotion of tissue growth. Other related areas are BioMEMS (MicroElectroMechanical Systems), microfluidics and chemoresponsive surfaces and systems.

The capability required includes pre-commercial scale synthesis of materials (such as biological, polymer, organic, inorganic and inorganic-organic hybrid materials), design skills (eg. micro-electronics, microfluidics and micro-mechanical-systems), a range of microfabrication and nanofabrication techniques for polymers, silicon and glass inter alia, and surface modification equipment to provide the desired functional behaviour. The fabrication and surface modification processes generally must be carried out in clean room environments at positive pressure, while the facilities to handle bioactive agents frequently require clean rooms at negative pressure. Ideally, these rooms should be co-located to minimise transport and handling of the products between processes.

Some of the technology areas where this capability is required include implants, biomedical devices, biosensors, chemosensors, tissue growth scaffolds and controlled release vehicles for biologically active molecules.

#### 5.4.2.2 Rationale

Australia has a world-class scientific and engineering research community in this area, with a reasonable track-record in commercialising R&D. The intention is to move this commercialisation track-record from a ranking of reasonable to one of world's best practice.

Australia has traditionally been strong in research relating to the biological/materials and biological/materials/electronics interfaces. Common concerns and frustrations expressed by R&D personnel are the time and difficulties associated with producing pre-commercial quantities of materials and samples of fabricated components, and the limited capacity to rapidly make prototypes for testing and further research. The equipment for the individual steps in making some products exist on a one-off, laboratory-scale in Australia but they are scattered and access is restricted.

#### 5.4.2.3 Infrastructure/support requirements

To overcome this problem, additional investments could be made in supporting the establishment of one or more comprehensively equipped facilities where the required pre-commercial production processes are housed under one roof. A national user facility could be established with the entire range of equipment, to provide a fully-integrated approach to the development process, from materials selection or creation through to pilot-scale manufacturing. Alternatively, the infrastructure required for each of the areas of bulk biomaterials, surface chemical modification for bio- and chemo-applications, and device fabrication may be sufficiently different to be able to have three separate specialist facilities.

The investment strategy would desirably cater for operating costs and costs associated with maintaining and upgrading existing equipment as well as for the costs of purchasing new

state-of-the-art equipment. Provision of facility staff with cross disciplinary skills and the networks to promote collaboration with experts in other fields would be important, as would an open peer-reviewed scheme to provide access to the infrastructure on the basis of the excellence of the research being proposed. Equipment from existing sites could be transferred to the facility(-ies) in order to consolidate the infrastructure.

### 5.4.3 Micro/nanofabrication enabling microelectronics, photonics, optoelectronics and integrated optics

#### 5.4.3.1 Description

A wide range of systems developments are underpinned by key device capabilities arising from micro/nano electronics, photonics, optoelectronics, microfluidics and integrated optics. Micro/nanofabrication generally centres on the capability to structure inorganic and in some cases organic materials on micron-to-nanometre scales.

This capability incorporates:

- Materials growth by a range of techniques including Molecular Beam Epitaxy (MBE), Metal-Organic Chemical Vapour Deposition (MOCVD), plasma-enhanced, laser and other forms of CVD, various forms of thin film deposition including thermal, electron-beam and laser evaporation, rf plasma and laser sputtering techniques; techniques for forming bulk materials based on batching and melting, including casting and rotational casting;
- Optical fibre fabrication in a range of materials by drawing preforms fabricated using techniques such as Modified Chemical Vapour Deposition (MCVD), extrusion, stacking and machining;
- The means to modify such materials and fibres including the use of microfluidics, high and low energy ion implantation, in some cases with nanoscale precision;
- The means to spatially structure the material or fibres on micron to nanoscales including electron-and ion-beam and optical lithography, imprinting and embossing, plasma and other forms of dry etching, as well as conventional wet etching, laser machining, and unique techniques associated with organics;
- A range of in-situ and post-processing nanoscale diagnostics;
- The processes of structuring, for example lithography including fabrication of masks and mask alignment and extrusion; and
- Pre-and post processing of samples including dicing, polishing, annealing, metalising, wire bonding, optical-fibre pigtailing and other forms of device integration.

The vast majority of these techniques must be undertaken in high-level clean-room environments.

#### 5.4.3.2 Rationale

Research in micro/nano electronics, photonics etc, which collectively represents a major research strength of Australia is necessarily underpinned by a range of sophisticated micro/nanofabrication facilities. Extending our capabilities to make real micro and nano-electronic, photonic and optoelectronic devices in Australia offers the opportunity to develop internationally competitive technologies with significant potential for direct commercial outcomes.

Current world-class research in Australia spans the “core” semiconductor materials technologies of silicon, the III-Vs (GaAs, AlGaAs, InGaAs etc and increasingly GaN, GaAsN, InGaAsN etc), mercury cadmium telluride and related materials, and the key optical materials technologies of lithium niobate, silica, fluoride and chalcogenide glasses (including advanced and microstructured optical fibre technologies).

There are leading edge research groups in all mainland Australian states with particular concentrations of effort in Perth, Melbourne, Canberra, Sydney and Brisbane that are supported by a range of small, but good quality specialist facilities, equally widely distributed. Although there are several formal and informal networks which assist in communication between some of these facilities and to some degree in providing access to the facilities, the national infrastructure for micro/nanofabrication is scattered, uncoordinated, patchy and generally lacking critical mass. Most of the existing facilities are under resourced and their inability to fully support operating costs restricts capacity and therefore access.

### 5.4.3.3 Infrastructure/support requirements

It is apparent that there remain significant gaps in Australia's micro/nanofabrication capacity and capability. A national approach through NCRIS to providing the infrastructure required in this area might comprise several key elements:

- Support of existing distributed facilities through funding of operating, maintenance and expansion/enhancement costs;
- Establishment of new facilities to fill critical gaps in capability[4];
- Provision of overall management, integration and coordination skills;
- Support emerging research strengths to incorporate them into a National Capability and extract optimal value from them

A specific model for national infrastructure might take the form of fully equipped and supported micro/nanofabrication clean-room facilities located in at least 3 capital cities with a range of satellite specialty facilities located elsewhere in those cities and in other nodes around Australia. The operation of the satellite facilities under this model could be supported as part of the national facility and access to them available for qualified researchers on a nationally managed basis. At the very least, access to clean-room facilities fully equipped for materials development, standard micro/nanoprocessing, diagnostics and fibre and device fabrication at acceptable cost to researchers would be a minimum requirement.

Implicit in the proposed model is much improved leveraging of existing facilities.

### 5.4.3.4 NCRIS Committee recommendations

The NCRIS Committee recommends that work commence as soon as possible, through an appropriate facilitator, to bring forward a coordinated proposal by

[4] Capability gaps might include lithium niobate fabrication, specialty techniques for nanofabrication of organic materials including laser-based rapid prototyping, techniques for surface functionalization of optical materials and fibres, and facilities for fabrication of devices integrating multiple materials technologies such as micro-optic active devices.

September 2006 to further develop Australia's fabrication capability. The Committee would expect the proposal to be well integrated with the Characterisation capability dealt with in 5.3 as well as other relevant capabilities in the Roadmap.

Feedback on the exposure draft of the Roadmap indicated a high level of support for the three components of the capability and that the research community wants specialist needs to be adequately catered for (for example emerging bio-nano fabrication applications).

## 5.5 Biotechnology products

### 5.5.1 Description

Bioproduct development relies on the efficient and controlled use of microbial cells, cells from animal and plant sources, and cell components. Recent scientific advances in fields such as genomics (the understanding of the genes and gene activity in cells), proteomics (the understanding of the proteins present in cells and being made by cells) and metabolomics (the profiling of all cellular metabolites) are now opening up the field of metabolic engineering, where the genomics and proteomics of cells can be manipulated in a controlled fashion to improve the cells ability to make a specific bioproduct.

Bioproducts include, but are not restricted to, proteins, antibodies, plastics, recombinant biopharmaceuticals, nutraceuticals, vaccines and biomass conversion (bioethanol/biodiesel). They may constitute a final product in themselves or be a component of a more complex end product.

Key components of this capability include:

- Bioreactors and bioprocessing at precommercial scale for microbial, plant and animal cells;
- Downstream processing / product recovery; and
- Production of "smart surfaces" for stem cell growth.

This capability also requires access to physical, chemical and biological/biomolecular characterisation techniques.

### 5.5.2 Rationale

There is an increasing demand for biotechnology derived products and processes. The impact of such products will be one of the main technological drivers of the 21st century.

Primary manufacturing capabilities for the development of the active ingredients of biopharmaceutical products (i.e. recombinant proteins, monoclonal antibodies etc) in

Australia are currently limited. 2001 estimates[5] indicated that Australia's protein manufacturing capacity is around 1% of global capacity. Global demand is predicted to exceed supply in the immediate future, placing further constraints on the achievement of translation of discovery to market product and extending the timescale over which it occurs.

The potential to produce novel nutraceuticals and to convert agricultural waste residues (biomass) to fuels (bioethanol and biodiesel[6]) through fermentation technology would promote human health, reduce our dependency on fossil fuels, and enhance the sustainability of our agricultural sector. Applications and benefits of microbial fermentation research will also provide rational approaches to detoxify liquid wastes derived from human activities including those from the mining and chemical industries.

Australia has supporting infrastructure and expertise in a number of centres, but is heavily reliant on offshore capabilities (up to $60M in such business goes offshore each year). Strategic investment in appropriate facilities and supporting technologies would better position Australia to maximise the outcomes of its research and development activities.

The major market area for growth of biotechnology products is production of human therapeutics. The ability to provide pre-commercial amounts of new therapeutic biological products combined with the appropriate support structures to foster Phase I and Phase II clinical trial activity will allow Australia to bridge the gap between two of its most successful areas of research: drug discovery and clinical research.

### 5.5.3 Infrastructure/support requirements

It is envisaged that support for this capability be focused on the development of several centres of activity clustered around existing capabilities across Australia. A hub and spoke model is suggested incorporating separate hubs (pilot facilities) focused on types of cell products or cell lines such as GMP mammalian cell manufacturing, GMP microbial cell manufacturing and plant cell manufacturing with early biomanufacturing tasks carried out in major research centres spread across Australia. The hubs would need to enable scale-up and downstream processing as appropriate for their applications. Some of the requirements include:

*Bioreactors and bioprocessing*: A key requirement is the provision (and appropriate equipping and configuration) of a range of bioreactors which are suitable for both basic research and for parallel scale-up of bioprocesses (ranging from several to hundreds of litres) and pilot scale reactors up to a thousand litres in capacity

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[5] Kelvin Hopper and Lyndal Thorburn, 2001 Australian Bioindustry Review, Aoris Nova Pty Ltd, December 2001

[6] An initiative has already begun to establish an 'Australian Biodiesel Institute' to provide a national focus for research and development into the production, manufacture and benefits of biodiesel.

(allowing for a next scale of up to 10,000 litres for true manufacturing). The design, fabrication and optimisation of flexible plastic reactors will be of increasing importance as the new bioprocesses based on stem cells are developed.

*Downstream processing, product recovery*: State of the art equipment for downstream processing is necessary to complement the developments occurring in the bioreactor stage. Computer controlled protein purification equipment suitable for process scale-up, for example, is required to allow the flexible production of batches of material for early stage characterization and subsequent application. There would need to be flexibility, so that a range of unit operations are available, catering for the wide range of bioproducts currently under development. Facilities to allow research on protein formulation and stabilization are required, as well as the full range of recovery options such as lyophilisation, spray drying etc.

*Production of 'smart surfaces' for stem cell growth*: Specialist facilities are needed which are suitable for developing novel methods for the production of the highly porous polymeric scaffolds required for use in tissue engineering and drug delivery. This is a rapidly evolving field which includes work being carried out to create highly functional 'biomimetic' surfaces which allow specific cell-surface interactions within a three dimensional porous scaffold, such as the work on developing the 'artificial niche' for the controlled growth of stem cell cultures. In addition to scaleable mini-reactors, extruders and injection molders, electro-spinning systems are required to enable nanofibres to be fabricated from novel polymers. Photolithography equipment for micro-scale patterning and device fabrication is also required. Co-ordination with components of 5.4 – Fabrication should be considered. It is noted that infrastructure availability may limit strategies for development in the area of smart surfaces.

There is strong synergy between this capability and 5.2 - Integrated Biological Systems. One example is the need for national cell repositories and/or culture collections for specialist applications such as the neurosciences.

### 5.5.4 NCRIS Committee recommendations

The NCRIS Committee recommends that work commence as soon as possible, through an appropriate facilitator, to bring forward a coordinated proposal by September 2006 to further develop a biotechnology products capability.

It would be expected that that the facilitator would work closely with groups such as Biotechnology Australia and the Biotechnology Liaison Committee as well as relevant research groups. The Committee would expect the proposal to take into account current and planned State and Territory investments in this area and would encourage industry co-investment.

The proposal should take particular care to ensure that any proposed facilities meet industry regulatory requirements of cGMP when considering clinical product development and to demonstrate a consideration of the relative benefits of investment in access to overseas as opposed to national infrastructure.

**Important Note:**

There would be an expectation for multiple agencies and ultimately industry to assist in the development of this pre-commercial capability. Industrial siting of components of the capability should be considered to foster closer linkages and commercial outcomes.

## 5.6 Translating health discovery into clinical application

### 5.6.1 Description

The goal of biomedical research is to have a positive impact on human health. This generally requires clinical trials to be conducted. Moving from the research laboratory to the clinic requires proof of principle in humans. To achieve this in a seamless and timely fashion requires a set of pre-clinical capabilities able to be applied to therapeutic molecules, cell therapy, medical devices, biomaterials and viral and nucleic acid delivery (sufficient to meet regulatory and production standards) including:

- The use of animal disease models
- Biomarker models of drug action
- Small chemical drug and radiochemical compound development
- Protein-based drug and imaging agent development
- The scale up of materials to clinical trial quantities
- Whole animal imaging for pre-clinical studies of new therapeutics
- Testing facilities to establish stability, delivery mechanisms and toxicity.

The above capabilities are not intended to include full scale development or manufacturing, activities which should be the responsibility of industry. Nonetheless, pre-clinical work should be performed mindful of the possible need to conduct full scale manufacturing at a later date so as to obviate the need to repeat clinical trials.

### 5.6.2 Rationale

Australia has a strong base in basic biomedical and clinical research. What is frequently lacking, however, is the capacity to move from the laboratory to the clinic. To capture the full value of Australia’s public and private investment in health research, pre-clinical capabilities need to be up to international standards and accessible in a timely fashion.

Moving from cellular or animal systems to humans requires skills and infrastructure different to those used in the biomedical discovery phase. Lack of access to these capabilities is a major issue and barrier for Australian biomedical research and industry. The capabilities that are available are spread across a number of institutions and are primarily dedicated to the needs of those institutions or are only made available on a fee-for-service basis that most researchers cannot afford.

The consequence is that too often basic research discovery either fails to proceed to the clinical stage or is sold too early for Australia to participate meaningfully in the returns.

Where local companies are involved in the development of biomedical discoveries, they tend to struggle because the scale and complexity of pre-clinical capabilities needed is difficult to provide in an environment where capital is scarce. Developing this capability in the public sector will therefore provide significant assistance to the local biotechnology industry by helping SMEs through the risky stages of development.

### 5.6.3 Infrastructure/support requirements

The need has been identified for a co-ordinated and integrated approach that addresses the gaps in the establishment, or barriers to the use, of pre-clinical capabilities in Australia. Some components are common with capabilities already described such as gene mapping and gene functions in 5.1, animal disease models, phenotyping, whole animal imaging and biological collections/libraries in 5.2 or provision of GMP grade biotechnology products and scale-up of materials to clinical trial quantities in 5.5.

Some investment in new physical infrastructure to address gaps is required as well as better integration and accessibility of existing infrastructure, and the removal of cost barriers. While it seems likely that funding to establish a 'virtual' network of pre-clinical research facilities, based on existing capacity and strategically enhanced to address gaps, would provide a partial solution to this problem, purpose driven facilities may be needed to drive early stage clinical trials.

Specific areas of pre-clinical capability requiring additional investment and coordination (taking into account the Pharmaceutical Action Agenda and related gap analyses) include:

- Creation of a national compound and screening library network that would fit into a pipeline for drug development.
- Preclinical development of molecules with therapeutic potential;

- Preclinical testing facilities (i.e. pharmacology and toxicology safety testing and testing of biomaterials, medical prothesis and cell-based therapies). There are currently gaps in this capability in universities (where it primarily resides) due to lack of pre-clinical focussed capacity and relevant skills;
- Formulation – pilot studies and production of clinical standard batches that can be used in safety pharmacology/toxicological assessments;
- Non-clinical aspects of drug development (i.e. scale up and manufacture). The priority capability for Biotechnology products (5.5) will help to address this gap; and
- Web-based trial data management systems to support later stage clinical research and clinical trials coordination.

### 5.6.4 NCRIS Committee recommendations:

Responses to the Exposure Draft of the Roadmap indicated strong support for this capability in a large cross-section of the research community but also a diversity of opinions as to appropriate investments. The Committee suggests that stakeholders in this area should continue to work towards clarification of the issues and needs.

The NCRIS Committee recommends that this capability be reviewed for possible implementation in 2007.

## 5.7 Population health and clinical data linkage

### 5.7.1 Description

A significant quantity of health-related data is collected in Australia that could potentially be a valuable research resource if it were better integrated and linked. Elements of this capability include the ability to:

- Link data from existing research studies and other sources of medical information (including administrative sources);
- Provide a focal point for Australian involvement in major international research collaborations, data pooling and studies involving up to millions of subjects;
- Support individual researchers and institutions to link and use longitudinal health-related datasets, and engage in multi-centre studies;
- Build the capacity of the research community to analyse and draw out the clinical implications of the linked information, by providing training opportunities for population health scientists and assisting in the development of measures and methodologies for longitudinal studies;

- Analyse, understand and develop protocols for responding to the legal, regulatory and ethical issues attending the linking of records and the conduct of longitudinal research; and
- Develop strategies and proposals to further invest in this capability as needs and opportunities arise.

### 5.7.2 Rationale

Australia has significant existing strength in bio-medical and public health research. It collects large amounts of health-related information via the health insurance, pharmaceutical and medical/hospital systems , as well as through research studies. However, this information is largely unlinked. Australia is falling behind other countries, where population health indices are being linked with administrative datasets and biological data.

This is imposing significant costs. To take one example, opportunities to quickly identify, and thus prevent or minimise harm from, inappropriate drug use are being lost because data on drug prescriptions is not linked to data on subsequent adverse health events.

A relatively small investment (in relation to total health costs) could leverage great research value from extant datasets, whether they be from research studies, disease registers, tissue banks, gene banks, bio-repositories, screening programmes, exposure records, clinical or pathology records. This in turn would facilitate identification of opportunities for prevention through avoidance of hazard, including iatrogenic harm. It could also help identify opportunities for reducing health system waste (eg. from non-performing drugs and procedures).

The capability would complement the activities and powers of agencies such as the Australian Bureau of Statistics and the Australian Institute of Health and Welfare. It would benefit a number of key sectors, including:

- *The health care system* - leading to greater effectiveness by facilitating economic studies of strategies, systems, and therapies;
- *Bio-medical researchers* – affording bio-medical researchers with opportunities to link molecular and cellular measures to health and disease precursors, processes and outcomes;
- *Clinical researchers* – enhanced capability would provide premorbid measures or specimens that could explain response to therapy, thus enabling better targeted therapy;
- *Health agencies and organisations* – the capability would support agencies and organisations involved in developing and conducting programs to prevent disease and injury including those focusing on socially disadvantaged populations; and

- *The pharmaceutical industry* – the pharmaceutical industry may buy materials and data for its own studies, thereby helping to sustain the capability.
- *The veterinary profession* - given the number of human drugs used clinically in animals.

Support for this capability offers the potential for substantial returns at relatively low cost in an area of central concern for the research and wider Australian communities. Developing it effectively will require careful planning. It is recommended that an early start be made to this planning to enable the benefits to flow as quickly as possible.

### 5.7.3 Infrastructure/support requirements

There is widespread support for developing this capability. Initiatives have already begun in several jurisdictions and there is clear potential for a coordinated national approach. One possibility is that the capability could be modelled on the system that is being implemented in Western Australia by Data Linkage Australia in which linkage of records occurs through a third party to minimise ethics and privacy concerns. A national system might comprise a network of such data linkage units with oversight by a coordination authority provided with both funding and staff capable of providing both intellectual leadership and administrative support.

It would ideally have the capacity to become a one-stop-shop, creating/endorsing national standards/conventions in the conduct of linkage studies and working with existing health and statistical agencies. One of its key challenges would be to communicate/advocate in relation to the public benefits of health data linkage research and seek support from agencies with a stake in its outcomes. Strong leadership, communication and engagement with the public and data owners will be required to encourage data owners to share their information, and to build protocols and public trust relating to the handling of privacy and other sensitive legal and ethical issues.

The development of this capability would need to be closely coordinated with the work of AHREC in relation to privacy, the State and Territory Governments, the Department of Health and Ageing, Medicare Australia and the National E-Health Transition Authority, which has responsibility for overseeing the implementation of e-health in Australia, including the secure electronic use of medical information.

Australia should also give some thought to the development of large-scale and longer-term initiatives for genetic research in order to best position itself in the future to draw potential benefits from genetic and health data linkages. One option which might be considered is investment in a “Biobank” initiative such as those in the UK and Europe and currently under consideration in the USA.

### 5.7.4 NCRIS Committee recommendations

The NCRIS Committee recognises that progress has been made in some jurisdictions towards defining and developing this capability. However the Committee considers that further work is needed to understand the requirements of a potential national capability which coordinates effectively across jurisdictions.

The Committee therefore recommends that support be provided for stakeholders to further scope issues and options related to this capability during 2006, leading to the development of a full investment proposal through facilitation commencing later in 2006 or 2007. The Committee suggests that relevant sections of the research community should be consulted to identify how best to progress work on this capability.

## 5.8 Networked biosecurity framework [7]

### 5.8.1 Description

Responding to emerging infectious diseases, whether related to unknown agents, those arising from genetic drift or agents potentially used for bioterrorism, requires a multi-disciplinary capability. This capability involves being able to anticipate – that is survey and rapidly diagnose – then contain and respond to the threat. It has a strong research component as the potential threats, and the mechanisms required to manage them, are diverse and constantly changing. The capability needs to encompass human, animal, plant and aquaculture areas.

Discipline specialists supporting this capability include entomologists, ornithologists, taxonomists, infectious disease physicians and veterinary specialists, microbiologists, virologists and molecular biologists.

A multidisciplinary capability, drawing together expertise across these disciplines, would be based on cutting-edge infrastructure and trained personnel who are ready and able to act in emergencies in different geographic locations, investigate new strains of pathogens, and participate in appropriate surveillance studies of known pathogens of potential threat to Australia within countries to our immediate north.

### 5.8.2 Rationale

New diseases and strains of pathogens with the potential to harm humans and economically important livestock or crops are continually emerging, both nationally and internationally. Recent examples include sudden acute respiratory syndrome (SARS) and ‘bird flu’. Bioterrorism is also a recognised threat.

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[7] In this context, biosecurity relates to emerging infectious disease, bioterrorism and forensics.

Vector borne diseases not frequently seen in Australia are becoming more common and drug resistant organisms such as tuberculous are on the increase and taking human lives. The continued threat of emerging infectious disease represents a high risk to Australia's position as a 'safe' country.

As a large island nation, Australia has some natural geographic barriers to infectious diseases emerging overseas. However the risk and spread of such diseases cannot be eliminated due to genetic variation, movement of birds and insects, movement of humans, population and behavioural factors, and climatic change.

There are few research centres in Australia regularly undertaking research on unknown pathogens, development of rapid diagnostics, rapid field based tests for such emerging agents, remote detection of bioterrorism agents or molecular forensics (or have the personnel or range of disciplines needed available).

### 5.8.3 Infrastructure/support requirements

Basic laboratory infrastructure and distributed PC3 and PC4 containment facilities already exist in Australia (in a suitable geographic spread). These facilities are used for a range of human, veterinary and defence purposes depending on local circumstances. There is some top-end capability in specific centres and discipline focussed expertise in centres around Australia for infectious diseases of humans, animals, plants and aquaculture. However, the capability requirements to support the four areas are somewhat different. Not all facilities are suitably equipped with the range of equipment needed for modern molecular diagnostic testing and few have a multidisciplinary networked team. In short, few centres have the range of facilities and expertise required to respond optimally to emergency situations or the emergence of new human, animal or plant disease pathogens.

A collective effort to develop a co-ordinated multidisciplinary capability in this area is needed to ensure that Australia is adequately prepared. Linkage of infrastructure and expertise through appropriate data bases, early posting centres and other information technology requirements would be integral to the delivery of an integrated capability both within Australia and as part of a global response.

This capability might be based on networked infrastructure that builds on existing national and state/territory facilities (including PC3 and PC4 containment facilities). It is envisaged that different laboratories within the network might specialise in different focus areas such as the development of reliable rapid diagnostic agents for particular diseases or the testing of those agents or plant health.

It would be anticipated that the states and territories would continue to ensure that they had appropriate medical and veterinary infectious disease personnel in such centres, and that the Commonwealth departments with responsibility for health and agriculture would maintain and potentially expand their current activities to complement the presence of the infrastructure.

While there is a current shortage of taxonomists, entomologists and some other expertise that is required, such expertise would be stimulated by the development of a networked capability in Australia and needs to be addressed in the investment strategy.

There are strong synergies between this capability and components of 5.1 – Evolving biomolecular platforms and informatics, 5.2 - Integrated biological systems (models of disease, phenotyping and biological collections) and 5.15 – Next generation solutions to counter crime and terrorism (diagnostics and forensics). There will need to be coordination in the development of proposals addressing these areas to avoid duplication and to take advantage of synergies. Close coordination with State and Territory Governments and the Australian Biosecurity System, currently under development, is required.

### 5.8.4 NCRIS Committee recommendations

The NCRIS Committee recommends that work commence as soon as possible, through an appropriate facilitator, to bring forward a coordinated proposal by September 2006 to further develop a networked biosecurity framework as outlined above.

The Committee recognises that significant progress has already been made in this direction through the cooperation of several state governments and the CSIRO (see exposure draft submission 56). The Committee suggests that this work should form the core of a broader national proposal.

## 5.9 Heavy ion accelerators

### 5.9.1 Description

Heavy ion accelerators have become the central tool for fundamental investigations of nuclear structure and nuclear interactions. They also provide capacities for characterising and modifying materials that are useful in many research fields and disciplines.

Australia currently has accelerator facilities at the ANU (whose Heavy Ion Accelerator Facility provides Australia's premier nuclear physics experimental facilities) and at the Australian Nuclear Science and Technology Organisation (whose Ion Beam Analysis Group provides a national focus for applied research in Ion Beam Analysis and Accelerator Mass Spectrometry, complemented by the Accelerator Mass Spectrometry program at the ANU). Current investment in the ANU facilities is in excess of $50 million, built up over decades through a combination of University funds, ARC project grants and other sources. At ANSTO the capital investment in the two accelerators is $12M, also built up over decades through Government, university and ARC funding.

### 5.9.2 Rationale

Heavy ion accelerators are useful in a wide range of research disciplines and application areas. Examples include the analysis of innovative materials, research in the environmental, biological and life sciences and archaeological and heritage studies. Australia's facilities at the ANU and ANSTO provide a vital resource for the Australian research community and industry, as well as being essential for postgraduate and postdoctoral training which feeds personnel into research and academic institutions; applied-science areas including diagnostic, therapeutic and nuclear medicine; nuclear safeguards and security; mining and other industry around Australia; environmental management, water, soil erosion; and policy analysis and defence intelligence.

Australian research has a solid international reputation[8] in both basic nuclear physics and the applications of heavy ion beams. There is a strong case for viewing Australia's accelerator facilities, and their accompanying expertise in Accelerator Science and Nuclear Physics, as key, strategically important national assets. In addition, the availability of local research facilities (enabling the conduct of internationally competitive research in this area in Australia) has been crucial in building the credentials of Australian researchers and thus securing access to overseas facilities, which are oversubscribed. Currently, however, limited resources are directed at the support of the proper operation of Australia's facilities as national facilities.

### 5.9.3 Infrastructure/support requirements

There is a need to more effectively exploit the capacity of Australia's Heavy Ion Accelerator facilities (and the expertise associated with them) to support enhanced national and international research programmes and meet the needs of a wide range of disciplines and application areas.

To ensure the continued operation and optimal utilisation of Australia's heavy ion accelerator facilities and the expertise associated with them, ANU and ANSTO facilities should be restructured and operated as a National Facility. The restructuring should be accompanied by an upgrading of the existing facilities through the enhancement and development of accelerator and beam-line instrumentation to develop their full capacity.

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[8] Australian researchers have strong publication records in high-profile international journals and are sought-after as experts, reviewers and consultants by similar laboratories overseas and key organisations such as the International Atomic Energy Agency (IAEA). Australian research has had a significant impact internationally, influencing for example, a re-direction in the study of heavy ion fusion as reflected in the US Long-Range Plan for Nuclear Science, and at the other extreme, developing a leading edge capability for Accelerator Mass Spectrometry with both fundamental and commercial applications

Such a national facility would: provide technical, operational and administrative support for its Australian and international users; expand links to key overseas facilities in Germany, Japan, France, the USA and Canada; support university-based training in nuclear physics and the application of nuclear techniques; and foster the development of closer linkages between ANSTO and academic institutions.

### 5.9.4 NCRIS Committee recommendations

The NCRIS Committee recommends that this capability be reviewed for possible implementation in 2007.

## 5.10 Optical and radio astronomy

### 5.10.1 Description

Access to the current and next generation of optical and radio telescopes are the key capabilities that will underpin the ability of Australian astronomical researchers to produce world-class research and innovation.

The current generation of 8-metre optical and infrared wavelengths telescopes (including the two 8-metre telescopes that comprise the Gemini Observatory) will remain the primary earth-bound optical instruments for the next decade. Australia, one of seven partners, joined Gemini in 1998. Gemini North in Hawaii began observations in 2000 followed by Gemini South in the Chilean Andes in 2002.

The next generation of earth-bound optical telescopes (dubbed extremely large telescopes or ELTs) are currently in the planning/development phase and will begin to come on stream in around 10-15 years. Similar planning is underway in relation to radio wavelength observing, with international efforts appearing to coalesce around the proposed Square Kilometre Array (SKA) project which, if it proceeds, would be operational in its full form in around 2020.

### 5.10.2 Rationale

Astronomy is one of Australia's highest impact sciences. Australian astronomers have played leading roles in recent major discoveries, including the acceleration of the universe, the existence of dark energy, a new type of galaxy, a unique double pulsar, and planets orbiting other stars. Our high international standing in astronomy helps support public interest in science and provides powerful evidence to the rest of the world of Australia's scientific and technological capacity. Astronomy is a rapidly evolving field in which continued investment is essential in order to keep pace with global developments.

Development of infrastructure for astronomy involves significant collaboration with industry and generates technological spin-offs. Early investment in new projects is crucial to securing the most valuable elements of these technology development programs and maximising the spin-off benefits for Australia.

### 5.10.3 Infrastructure/support requirements

For Australia to remain a major international contributor to astronomy it is essential that we continue to have a strong presence in leading-edge international infrastructure, both the current and next generations. Australia also needs to maintain the domestic infrastructure which constitutes the bulk of observing capacity for Australian astronomers.

The Australian astronomy community has identified its priorities for infrastructure investment in the *Australian Astronomy Decadal Plan 2006-2015*. Consistent with that plan, the Committee considers that the priority areas for NCRIS investment in optical and radio astronomy should be (in no specific order):

- Additional support for the Anglo-Australian Observatory (AAT optical/infrared telescope);
- Delivery of the Square Kilometre Array (SKA) *Phase 1*[9] radio telescope facility; and
- Access to the equivalent of 20% of an 8m-class telescope through the existing Gemini partnership and through new telescope and instrument agreements.

It is expected that major instrumentation upgrades to Gemini and the development of the *SKA Phase 1* (with Australia in both cases playing a role in technology development) will deliver an order of magnitude improvement over existing capabilities in optical and radio astronomy world-wide. Australian participation in *Gemini* and *SKA Phase 1* would keep Australian astronomers at the forefront of astrophysical research for at least the next decade.

The NCRIS Committee recognises the importance to the astronomy community of participation in next generation of instruments, an ELT and full implementation of the SKA, but notes that investments in these are beyond the scope of the NCRIS program and will need to be dealt with through separate processes. In addition the timescale for the full SKA project puts it effectively beyond the horizon of the Strategic Roadmap.

The Committee considers the National Committee of Astronomy's (see exposure draft submission 51) recommendation that a Giant Magellan Telescope Landmark Facility Committee be established by relevant government, business and academy partners to work towards Australian participation in the GMT consortium has merit and encourages the parties to consider it.

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[9] Previously known as SKA Pathfinder

### 5.10.4 NCRIS Committee recommendations

The Committee recommends that the Australian Academy of Science's National Committee for Astronomy develop a detailed proposal by September 2006 for the implementation of this capability through a phased series of investments. The proposal would need to:

- clearly prioritise the infrastructure requirements and provide a range of cost options;
- provide a clear timetable for the investments; and
- recommend governance arrangements whereby the investments can be managed effectively and appropriately on behalf of the astronomy community.

## 5.11 Terrestrial ecosystem research network

### 5.11.1 Description

The ability to effectively monitor environmental parameters and interpret the associated data holistically is essential to understanding the key components of our landscape and how they function in an integrated manner. The challenge is to develop relevant and reliable datasets on the key components of our terrestrial ecosystems, i.e. our water resources, biodiversity and soils, which capture accurately their evolution and health over time.

### 5.11.2 Rationale

Soil and water are fundamental to the wealth we generate from our lands, while our unique biodiversity is adapted to our variable climatic patterns and holds the key to sustainable living on our continent. Our landscape is under threat from problems such as salinity, land degradation, serious degradation of water resources and loss of biodiversity, as well as from the often-negative impacts of pests, fire and climate change.

Landscapes are made up of multiple, complex, interrelated systems, which need to be understood and managed in an integrated way. For example, one important measure of the health of a landscape is the quantity and quality of water it receives. The quantity and quality of water that a landscape receives is in turn affected by wider climatic patterns and trends (influenced in turn by net emissions of greenhouse gases, especially CO2 and methane) together with more localised parameters such as topography and soils, vegetation cover, land use and depth of groundwater. Altering the vegetation cover in a catchment changes the habitat of its remaining biodiversity, the quantity and quality of water running off, and the volume and timing of flow pulses received by its rivers, affecting the plants and animals of the floodplain, river and estuary. Understanding interrelationships such as these, and effectively managing their impacts requires integrated, coherent data sets on a national scale providing accurate, reliable, measures of the state of key environmental parameters and how these are changing through time.

While significant investment is being made in collecting and enhancing the integration of terrestrial ecosystem data - a fact underlined in responses to the Exposure Draft of the Strategic Roadmap - much remains to be done.

### 5.11.3 Infrastructure/support requirements

One option (proposed by the Committee in the Exposure Draft of the Strategic Roadmap) would be to support the development of a *Terrestrial Ecosystem Research Network,* building on significant past and present initiatives and investment by both State and Commonwealth Governments and new technology developments. Such a network would deliver an urgently needed upgrading of the information base that underpins Australia's environmental research and environmental management efforts. It should be national in scope, comprising geographically distributed sensors providing real time, or almost real time, data streams using state-of-the-art communications technology. Monitoring could be undertaken both spatially and temporally to build understanding of how the environment is changing (and is likely to change in the future) both across regions and through time. The ability to process large quantities of information and to present information based on this data would require significant resourcing over time.

The data streams could flow into three hubs, focusing respectively on the areas of *water, soils and biodiversity*. The hubs would provide data repositories and state-of-the-art modelling capacity, delivering both data and value-added analysis for research teams and natural resources management agencies across the country.

In the case of water, for example, data aggregated and modelled in the hubs could relate to key parameters including stream flow, groundwater depth, evaporation rates, the flux of nutrients (phosphorus and nitrogen) driving downstream plant responses, levels of suspended solids (driving turbidity that affects how we use water as well as ecological processes), salt, carbon, agricultural chemicals and the consequent ecosystem responses. The biodiversity hub could provide a series of nodes, hosted by different regional institutions but with common protocols for data standards and reporting, with the capacity to provide broad access to biodiversity data that is collected from a number of programmes as well as to focus on national issues such as land degradation, sustainable land use, biodiversity loss and other topics. Finally, the soils hub could build on capabilities such as the Australian Soil Resource Information System, focussing on soil degradation and physical loss through salinity, sodicity, nutrient decline and erosion, and soil improvement through improved management processes.

While the envisaged network would provide for the development of these individual hubs, a desirable outcome and an important focus of any NCRIS investment would be their integration into a meaningful holistic picture of Australia's terrestrial ecosystems. As a first step towards this, the establishment of a series of more intensive long-term ecological research sites across Australia is suggested, encompassing both agricultural and natural areas and linked to the three key national hubs. Such research sites might build on related efforts within ecological/agricultural institutions, such as the Australian Collaborative Rangelands Information System (ACRIS), and would help us to understand how different ecosystems are changing over time and in response to external factors and conditions such as climate change and differing land use.

Responses to the Exposure Draft reveal strong support for action to improve the quality and level of collection and integration of data relating to Australia's terrestrial ecosystems. A number of respondents stressed the need for this action to take place within a framework that is cognisant not only of interrelationships within the terrestrial environment, but also of interrelationships between the terrestrial environment and the coastal, marine and atmospheric environments. There is a recognition of the magnitude of the task – not only intellectually (given the complexity of the systems being studied) but also organisationally and politically (given the number of jurisdictions and agencies involved and the number of initiatives that are underway).

### 5.11.4 NCRIS Committee recommendations

Given these complexities, the Committee considers that it is unlikely that an "investment ready" proposition could be developed in time for NCRIS funding to commence in 2006/2007. The Committee understands that considerable effort will be required to work through these issues, but considers that this effort is worthwhile and should be initiated, with a view to developing a proposal for consideration during 2007.

The Committee therefore recommends that support be provided for stakeholders to further scope issues and options related to this capability during 2006, leading to the development of a full investment proposal through facilitation commencing later in 2006 or 2007. The Committee suggests that relevant sections of the research community should be consulted to identify how best to progress work on this capability.

## 5.12 Integrated marine observing system

### 5.12.1 Description

In order to understand and ensure the long-term health and productivity of Australia's marine estate and related industries, and to predict climate variability and change, it is essential that Australia has the capacity to accurately and rapidly detect and predict changes in the ocean environment, coastal ecosystems and marine living resources. This requires capabilities in: collecting data (both remotely and via research vessels); storing, managing and making accessible the data that is collected; and modelling to support the interpretation of data and inform predictions. These capabilities need to be coordinated in a nationally consistent and coherent manner.

### 5.12.2 Rationale

Under the United Nations Convention on the Law of the Sea (UNCLOS), the combination of our 200 nautical mile limit and extensive “claimable continental shelf” means that 70% of Australian territory will be ocean. Australia’s marine jurisdiction is one the world’s largest, and also one of the least explored and understood. To date, marine information needs have largely been addressed in a piecemeal manner, on a sectoral or institutional basis, resulting in observations that are limited in scope, and fragmented in time and space.

Australia has excellent research capacity in ocean ecosystems and marine environments, but urgently needs research infrastructure to support an improved understanding of its marine environment and the influence the marine environment is having on the atmosphere and terrestrial environments. For example:

- More than 40% of the anthropogenic CO2 is currently absorbed in the Southern Ocean. Understanding oceanic processes is critical to understanding the impact of the anthropogenic CO2 in climate change.
- Climate variability is hugely affected by El Niño, a disruption of the ocean-atmosphere system in the tropical Pacific having important consequences for weather and the climate around the globe.
- Sensible management of the marine environment requires accurate and timely information.
- Predicting the timing and regional impact of climate change is critically dependent on observations of the ocean.

Upgrading our existing capability would also provide information about our massive store of biological and seabed resources and the unprecedented stresses to which our ocean ecosystems and marine environments are being subjected. More broadly, however, it would underpin applications across national security, marine safety, marine resources and related industries, coastal ecosystem management, and climate prediction, while at the same time ensuring that Australia meets its international obligations for marine management under UNCLOS.

### 5.12.3 Infrastructure/support requirements

To meet this need an *Australian Coastal and Ocean Observing System* should be developed.

The system would integrate data from remote sensors (including satellite systems deployed by northern hemisphere nations) and automated in situ observing platforms with advanced modelling techniques. Such systems are becoming routine in the northern hemisphere with the development of cutting-edge technology that is revolutionising marine research and observation capacity. Integral to the system would be processes to store, quality control and make readily accessible its data and associated information.

The system would comprise two linked and interdependent components - blue-water and coastal - and include engagement in related international programmes (e.g. the Integrated Ocean Drilling Program (IODP) [10] and the Global Ocean Data Assimilation Experiment [11]). The blue-water component would primarily serve climate and ocean forecasting, but would be closely linked and integrated with the coastal component, which would focus on coastal and continental shelf ecosystems (note that an additional highly important and desirable outcome of any developments would be interaction and linkage with parallel terrestrial monitoring networks and associated data). The coastal component might initially include intensive observing systems in several regions, with lower level systems in other areas that could be upgraded as needs, resources and testing indicate. Systems for gathering and storing coastal and marine observational data, and associated modelling, should be capable of interfacing smoothly with corresponding systems dealing with terrestrial ecosystem and atmospheric data, to facilitate understanding and management of the interrelationships between these domains.

The infrastructure most urgently needed for this system would include:

- Access to research vessels - while the importance of such vessels was stressed in a number of responses to the Exposure Draft, the cost of acquiring large research vessels is likely to be outside the scope of NCRIS;
- Automated and ongoing *in situ* observing systems delivering products to the user community; and
- Participation in IODP.

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[10] IODP focuses on: (a) solid earth cycles and geodynamics; (b) environmental change, processes and effects; and (c) the deep biosphere and the sub-seafloor ocean.

[11] Participation requires the capability to measure ocean profiles of temperature, salinity and other properties, ocean currents at key choke points and air-sea fluxes of momentum, heat, freshwater, CO2 and other properties. A key component would be the deployment of an array of profiling Argo floats as the Argo array in the oceans near Australia is notably sparse compared with other regions.

There is strong support for developing an Australian Coastal and Ocean Observing System. Considerable thought has already been invested in how such a system might be developed, under the aegis of the Oceans Policy Science Advisory Group, an Australian Government advisory body whose role includes promoting coordination and information sharing between Australian Government marine science agencies and across the broader Australian marine science community.

### 5.12.4 NCRIS Committee recommendations

The NCRIS Committee recommends that work commence as soon as possible, through an appropriate facilitator, to bring forward a coordinated proposal by September 2006 to deliver an Australian Coastal and Ocean Observing System. The Committee recommends that the Ocean Policy Science Advisory Group (OPSAG) play a role in overseeing the development of the proposal.

## 5.13 Structure and evolution of the Australian continent

### 5.13.1 Description

The capacity to obtain accurate information on the geological structure of the Australian continent is an important capability supporting both our understanding of fundamental geological processes and structures and the manner in which they have evolved over time.

Important elements contributing to this capability include:

- Geophysical imaging – (both seismic and non-seismic) providing detailed information on physical structure and processes;
- Geochemical analysis – providing information on the chemical composition of geological materials (both solid and liquid); and
- Geophysical modelling – providing advanced earth simulation from micro to global scales and facilitating the interpretation of data.

### 5.13.2 Rationale

From its ancient rocks and unique tectonic setting to its network of interdependent modern environments, the Australian continent is a natural laboratory for the study of processes that have shaped the modern world. Its evolution over long periods of time has determined its distribution of the abundant mineral and energy resources, and its vital supplies of soil and water upon which we depend. Detailed scientific knowledge of the Australian continent's geological structure and evolution makes a fundamental contribution to: understanding the emergence of the modern environment and the global changes that have shaped it; comprehending the complex interactions that control the stability or instability of modern earth systems upon which our lifestyle and habitat depend; locating the supplies of minerals and energy resources; and anticipating and responding to major natural disasters.

Research in this area is critical for the economy and wellbeing of Australian society, and will remain so for the foreseeable future. Australian researchers have world-class expertise, producing over 5% of the global output of geoscience publications and having a commensurately disproportionate influence in terms of citations, the highest for any branch of science in Australia. However, the effectiveness of research in this area is strongly dependent on the infrastructure available to geoscience researchers and the degree to which they are able to access it. Currently, Australian researchers are being constrained by significant gaps in major research infrastructure, arising largely from the lack of a coordinated approach to its development.

### 5.13.3 Infrastructure/support requirements

Priority areas of infrastructure development to support this capability have been identified for both the short and long-term.

An important short-term opportunity exists for dramatically increasing the impact of existing national infrastructure in key areas of capability such as seismic imaging and computational modelling of earth processes, and for making them more accessible. This is likely to produce the most immediate benefits in the short term in the most cost-effective manner.

Longer-term options that will also considerably contribute to our understanding of the structure and evolution of the Australian continent include: a national geotransect; a National Geospatial Reference System (NGRS); and a network of ocean-bottom seismometers. Among these, particular support was expressed in responses to the Exposure Draft for an NGRS, drawing attention to the potential of such a system to deliver benefits to a wide spectrum of the research community, as well as the geoscience community specifically.

### 5.13.4 NCRIS Committee recommendations

The NCRIS Committee recommends that work commence as soon as possible, through an appropriate facilitator, to bring forward a coordinated proposal by September 2006 to:

- Provide additional operational support to the two existing Major National Research Facilities (the Australian National Seismic Imaging Resource (ANSIR) and the Australian Computational Earth Systems Simulator) with a view to enhancing their accessibility and value as key national research infrastructure resources; and

- Support the geoscience community's longer-term infrastructure investment priorities, to be considered in the context of NCRIS funding from 2007/2008.

The Committee further recommends that support be provided for stakeholders to further scope issues and options for the development of a National Geospatial Reference System servicing both the geoscience community and the broader research community (and NGRS users).

## 5.14 Low-emission, large-scale energy processes

### 5.14.1 Description

There is a need to develop and deploy low-emission, large-scale processes for fossil-fuel and biomass based energy production, both globally and in Australia. Within Australia it is particularly important to address this need in a manner that is suitable to our unique conditions and which enables scale-up and testing of research outcomes.

Coal provides a major source of energy in Australia and around the world, and will continue to do so over the coming decades. Given this reality, the Committee considers it critical that ways are found to minimise the adverse environmental consequences of coal usage, and views this as the highest priority area for immediate NCRIS investment relating directly to energy production.

While the Committee considers that this should be the immediate priority for NCRIS investment, it recognises the importance and potential of non-fossil fuel based energy technologies such as wind power, solar power (such as photovoltaics), tidal power and geothermal, together with the expertise relating to these technologies (and their underpinning science) that has been built up in the Australian research community. Usage of these technologies is growing rapidly, but from a low base, suggesting that they will become increasingly important over the longer term, with their rates of uptake influenced, at least in the short term, by the extent to which their costs can be brought down to levels which are competitive with fossil fuels. The Committee notes that suitable infrastructure investments in other areas would, if implemented, provide platforms for developing and exploring technologies that could help bring down the costs of non-fossil fuel based energy (see, for example, sections 5.3.1, 5.4.1 and 5.5).

### 5.14.2 Rationale

While Australia has benefited for decades from its rich coal resources, the adverse climatic consequences of ever-growing greenhouse gas emissions from coal-based electricity generation extend to and affect Australia's water resources, biodiversity and natural treasures such as the Great Barrier Reef, while national and international policy responses to climate change threaten our continued use and national economic contribution of these low-cost resources.

Australia's public and private sector researchers have a well-deserved reputation for development of innovative technologies to support Australia's mining and minerals industries, as well as supporting Australia's electricity generators. However, we lack the capacity to undertake the further research needed to move beyond the laboratory scale. There are Australian technologies in these areas that are innovative (indeed step-change – for example in CO2 capture, mineral sands processing and coal/biomass gasification) but need progression to a meaningful scale to reduce technology risk sufficiently for commercialisation.

Currently, most research into next-generation, large-scale, low-emission electricity generation and minerals processing is being conducted in the USA, Europe and Japan by large equipment and utility companies, with government support. While Australia could simply import its technology in this area, to do so would be to forgo the prospects for commercialisation of Australian technologies in this very important area as well as to incur risks arising from the fact that imported technology will not have been developed for the particular types of coal found in Australia. Local research support will continue to be needed to avoid major loss of capacity due to fuel-related problems (as has happened and continues to happen for all Australian black and brown coal power stations) and to enable us to be "informed buyers" of technology that is imported.

Providing this capability would fill a major gap in Australia between laboratory bench-scale and *pre-commercial* scale facilities (including opening up for collaborative use some existing facilities). The government has recently opened for business the Low Emissions Technology Demonstration Fund (LETDF). This funding is expected to provide a relatively small number of large grants for the demonstration stages of pre-commercial scale facilities. The objective of the LETDF is to demonstrate the commercial viability of new technologies or processes or the application of international technologies or processes to Australian circumstances. NCRIS funding could complement LETDF projects by supporting earlier stage, more basic research on energy processes.

### 5.14.3 Infrastructure/support requirements

To meet this need, it is suggested that a capability be developed to:

- Adapt next-generation combustion and gasification processes for Australia's broad range of black and brown coals and ambient conditions;
- Demonstrate the operation at meaningful mid-scale level of locally-developed, step-change technologies for processing of our coal and mineral resources and capture of combustion emissions (particularly CO2);

- Support meaningful interaction in international research programs and projects relevant to exploitation of our Australian energy and minerals resources.

It is proposed that the capabilities developed be flexible enough to also allow demonstration of mid-scale processes for the utilisation and gasification of biomass resources.

A public-private partnership through joint funding of the capability proposed here would enable the current skill base in the area to support the transition of Australia's electricity and minerals processing industries to next-generation plants, while supporting the development of the next generation of local research personnel. There is considerable potential to leverage existing infrastructure in Victoria, New South Wales and Queensland (in particular) that complements or should become part of (with suitable upgrading) the proposed research infrastructure. International funding support has been provided in the past into Australian research projects in these areas, and would be likely to be available again to support the proposed capability.

Responses to the Exposure Draft show agreement on the importance of the overall need to develop and deploy low-emission, large-scale processes, but limited support for NCRIS investment along the lines outlined above. Support was expressed for Australian involvement in the International Thermonuclear Experimental Reactor (ITER) - see section 3.1). A number of respondents argued for investment in a broad portfolio of alternative energy options.

While the Committee agrees in principle that a "portfolio' approach is preferable, this is not feasible within the NCRIS funding envelope. Its view remains that the highest priority for action in this area is minimising the adverse environmental consequences of coal usage, noting that the investments proposed in relation to Characterisation and Fabrication should provide significant support for alternative energy research. That said, responses to the Exposure Draft did not provide an indication as to how a national, collaborative approach to the research infrastructure requirements in this area might be developed.

### 5.14.4 NCRIS Committee recommendations

Responses to the Exposure Draft of the Roadmap indicated strong support for this capability in a large cross-section of the research community but also a diversity of opinions as to appropriate investments. The Committee suggests that stakeholders in this area should continue to work towards clarification of the issues and needs.

The NCRIS Committee recommends that this capability be reviewed for possible implementation in 2007.

# 5.15 Next generation solutions to counter crime and terrorism

## 5.15.1 Description

Solutions and research capabilities in the forensic sciences are required that contribute to reducing the threat and impact of crime and terrorism.

Key capacities that are needed relate to the ability to:

- Accurately and rapidly detect, in the field, chemical, biological, radiological, nuclear and explosive (CBRNE) agents;
- Detect CBRNE agents at a distance or covertly;
- Vastly improve the rapid identification of suspects in property or volume crime cases through the delivery of forensic science solutions in the field;
- Sustain traditional forensic sciences and develop new solutions to meet emerging threats; and
- Improve information and intelligence through enhanced data management and data mining.

Responding effectively to the consequences of crime and terrorism also requires research capabilities focussed on issues such as protecting and preparing major infrastructure and improving emergency responses.

## 5.15.2 Rationale

On a global scale, Australia remains a relatively safe and crime free society, but this is being challenged by the emergence of a new form of terrorism and a continuing high level of domestic property crime. Crime and terrorism have the potential to undermine society at all levels, cause a major loss of life, cause significant economic havoc, and have a severe impact on tourism.

The Australian Government has invested in a number of recent initiatives to coordinate and support R&D with a focus on security and terrorism. These include the establishment of a Science, Engineering and Technology Unit to coordinate research and developments and the soon-to-be-established CBRN Data Centre under the Australian Federal Police. The National Institute of Forensic Services, working together with industry, has also been successful in attracting funding from the Australian Government for several pilot research projects as part of a broader innovation strategy.

Notwithstanding several recent investments in the forensic sciences, the inherent weakness is that the industry by necessity deals with the day-to-day practical case work issues. It is not a research industry, and relies on its ‘future solutions’ coming from the traditional research providers in academic institutions. If the forensic sciences are to be able to meet the operational challenges of the future, the next generation scientific and technological solutions must come from the research sector and that sector must give appropriate priority and emphasis to developing solutions to meet these emerging needs. There is a current significant capability gap in this area is compromised of both technologies and the management of information.

### 5.15.3 Infrastructure/support requirements

The key challenge is to ensure that the solutions developed are targeted in a practical way so that they meet the needs of industry and assist it in overcoming major impediments. For example, forensic laboratories are not able to process samples collected at property crime scenes in a timely manner, which results in repeat offending and delays in our criminal justice system.

Better assessment of potential evidence at the scene (in the field), with the ability to analyse samples such as DNA, drugs and fingerprints and to then search suitable databases remotely, has the potential to deliver more effective and quicker justice, to make people feel safer and with the added bonus that forensic laboratories would have the resources to better service serious and more complex crime.

Terrorism is an increasingly significant component of the work of forensic laboratories. New scientific and technological solutions will be needed to meet the rapidly evolving analytical challenges confronting forensic providers. Solutions will be needed that help anticipate, prevent, protect, respond and recover from such incidents.

In the area of consequence management of extreme events, there may be an opportunity to build a nationally significant research capability around the coordination efforts already underway between management agencies, emergency services and research organisations (such as the collaboration between the NSW Fire Brigade and CSIRO noted in exposure draft submission 130).

### 5.15.4 NCRIS Committee recommendations

The NCRIS Committee recommends that this capability be reviewed for possible implementation in 2007.

**Important Note:**

This capability is closely related to 5.8 - Networked biosecurity framework. While these capabilities need to be given separate focus and consideration, they should be developed in a coordinated manner.

## 5.16 Platforms for collaboration

All areas of modern research are heavily – and increasingly – dependent on technological platforms that are enormously enhancing the research community's ability to collect, share, analyse, store and retrieve information. These "platforms for collaboration" are continuing to develop rapidly, creating an ongoing flow of opportunities to enhance the quantity, quality and productivity of research effort.

In the Committee's view, investment in these platforms is critical to sustaining the standing of Australia's researchers and supporting the development of collaborative approaches to research that are both nationally focused and well connected with global research efforts. This was strongly supported in responses to the Exposure Draft.

As the needs for many of the specific enabling technologies (such as high-speed data communications) are shared by all disciplines, investment in them is best managed on a system-wide (rather than discipline-by-discipline) basis. This has particular ramifications for the humanities and social sciences. In the Exposure Draft, two suggestions for research infrastructure relating to the social sciences and humanities were canvassed *(Development of creative industries, digital content and applications*, and *Collaborative and strategic data fusion and model interoperability*). While the content of these suggestions is targeted to the social sciences and humanities, the broad form of the proposed solutions (aimed at providing an enhanced capacity to rapidly access, draw together, collaboratively consider and interpret information from multiple sources) is relevant to all disciplines. Because much (if not all) of what constitutes "research infrastructure" for the social sciences and humanities are specific applications of generic platforms, the Committee considers that the research infrastructure needs of these disciplines are best considered as part of a system-wide information management strategy.

Platforms for collaboration include the following sets of inter-related components:

- *Data storage management, access, discovery and curation* to improve interaction and collaboration;
- *Grid enabled technologies and infrastructure* to enable seamless access to the facilities and services required in various research fields;
- *Support skills* to assist researchers in developing and using this infrastructure effectively;
- *High performance computing* to allow analysis, modelling and simulation; and
- *High quality network access through high capacity bandwidth* to permit interaction with diverse data and computing resources.

These components are briefly discussed in the following sections.

### 5.16.1 Data access and discovery, storage and management

Many of the capabilities identified in this Strategic Roadmap will produce (for example through instruments such as synchrotrons or sensor networks) or depend upon large sets of data.

In addition to new sets of data, some identified capabilities will depend for their utility and success upon curation of and access to large collections of existing information resources, in a variety of formats e.g. print publications, databases, sound recordings, images, (photographs, paintings, x-rays) and repositories of non-bibliographic information.

Ideally, investment in platforms for collaboration should provide researchers with the ability to: gain access to information relevant to their field from a variety of sources seamlessly; exchange information collaboratively with colleagues; annotate their datasets or publications; and to manage and disseminate the results of their research through supported repositories.

Repositories have the potential to move beyond the traditional approaches, e.g. just for storing publications, to support innovative new forms of research data, collections and research output. Some possibilities include:

- Life cycle management of research and research results;
- Smart publications that link experiments, results and a range of documents that shorten and change the "publication cycle" (time to release new research);
- The ability to validate not only research conclusions but also research results; and
- The ability to allow other researchers access to original raw data – even for different purposes – or to provide stronger support for authenticity, authority and integrity of research.

In order to manage research outputs, many elements need to be in place. These include: appropriate hardware and software (the technology); supporting workflows, policy and regulatory frameworks and administrative arrangements; and resources, especially staff resources. In addition, there are copyright and other legal considerations, together with technical standards issues, including sustainability, that need to be considered.

In order to be exploited by search engines and data mining software tools much of the data, including experimental data, that will be exposed through the linkage of databases, needs to be annotated with relevant metadata providing information on provenance, content, conditions of use and so on.

Much of the work around data access has focussed on removing barriers to access, through technical mechanisms of software tools and hardware. Seamless access to information and other resources can be impeded however, particularly in a networked environment, if researchers are not mindful of intellectual property law. In many cases, there is no certainty. A key challenge for the future is to establish legal protocols that can allow access to, or downloading of, research to be clarified and simplified.

To enhance researcher effectiveness and facilitate easier access to research results and outcomes, it is also essential that electronic storage of research is consistent with internationally agreed technical standards.

#### 5.16.1.1 Data discovery and access

Investment is required to provide ready and collaborative discovery of and access to new and existing information. This is the key to the future of research in the electronic environment in which much research is conducted today. The objective is to enable researchers and readers to search, browse and discover resources within a repository and access them, either under controlled conditions or in an unrestricted way.

Elements of this capability that need to be addressed, in order to provide maximum commonality and utility to researchers across many disciplines and to best facilitate collaboration and accessibility, are those that provide the ability to:

- Identify, integrate, curate and where necessary, translate existing, distributed, and often disparate data collections / sets stored in different institutions;
- Provide seamless search interfaces across distributed archives i.e. develop data grids;
- Archive existing and future data for integration and reuse;
- Develop federated digital data libraries and where appropriate to link these with computational resources; and
- Convert data into compatible formats.

These are complex and difficult tasks that need to harness extensive resources in a strategic and sustainable manner that pulls together teams of people and leverages new technologies, such as distributed computing, for the benefit of the groups concerned. These archives may need to be organised to provide interoperability across heterogeneous metadata schemas. In some instances services will need to be built to allow simulation data to be retrieved from repositories or regenerated dynamically using computational services.

Australian researchers have been involved in developing some of these capabilities at both national and international levels, and this experience should be built upon in developing further and more integrated capabilities. For example, *BlueNet: The Australian Marine Science Data Network* is building infrastructure to enable the discovery, access and online integration of multi-disciplinary marine science data on a very large scale to support current and future marine science and climate change research, ecosystem management and government decision making. BlueNet will link the vast data repositories and marine resources that reside in eight universities with governmental institutions both in Australia and overseas. The BlueNet infrastructure will provide secure, long-term data archiving facilities, a platform for deploying novel data exploitation tools as well as the governance and institutional arrangements necessary to maintain an on-going, interoperable, accessible and flexible network.

#### 5.16.1.2 Data storage

Investment is also needed to provide reliable, efficient and accessible storage of research data in order to achieve the required effectiveness and collaborative outcomes for the capabilities identified in the Roadmap. Currently extensive holdings of research data are stored within personal archives, either on researcher desktops or on departmental/institutional servers. In these locations it is largely inaccessible, and inhibits collaborative research activity. A substantial subset of this type of data needs to be archived and curated for long-term preservation. The data in many cases is a complex mix of numeric, textual and image data and therefore the mechanisms for curation and access are necessarily complex. Furthermore it should be noted that such digital preservation requires the preservation not only of the data but also of the programs that are required to manipulate and visualise it.

With the increased production of data through modern research activity and the use of new research infrastructure, and with the outputs from simulations and the various instruments and sensors among the various research communities, infrastructure providing very large storage capacity is required to store and make accessible key research data.

This infrastructure will need to be built using hierarchical storage management for high speed online access. In many instances this will also require the linkage between disparate databases to build a sophisticated federation of databases. In others, there will be a need to ensure that there is high capacity storage, such as that provided presently through APAC.

#### 5.16.1.3 Data management

Presently there are a myriad of efforts to store and manage research data, largely based around institutions and, within institutions, around departments and individuals. The quantity of research data is growing rapidly. Investment is needed to ensure that this data (which is diverse in terms of size, complexity and location) is managed in a coherent way, so that it can be readily accessed when and as it is needed.

In all cases the provision and maintenance of institutional repositories – the software, hardware and services required to accept, store, make available online and manage a wide range of digital content, including the research output – are fundamental. Repositories will provide much greater functionality and support for collaboration, as well as exposing research activity in ways that have not been possible before, further increasing the return on investment in publicly funded research.

Furthermore, there are a range of issues to do with the management and sustainability of repositories in various domains, including e-sciences, grid computing and e-learning. There is an increasing occurrence of cross-discipline and cross domain communication. With this there is an accompanying need for interoperability and integration between distributed systems and services to support inter- and intra-institutional and cross-domain communication.

A number of projects have been initiated in Australia to provide the platforms and knowledge to evolve more comprehensive solutions.

For example, the *ARROW* project is developing software, based on the open source *FEDORA* software, to manage the full range of universities' research outputs, to support the reports submitted annually to DEST and to provide easier access to the material. The software will support the capture of content and its indexing in a research directory or directories, present a web version of the full directory, link from the directory level to full text and support the once-only creation of metadata and other information needed to report correctly and manage the directory, the repository and a resource discovery service. The *ARROW* project is building a sustainable solution by involving a library systems supplier to provide software development, installation, maintenance and training for the *ARROW* repositories

Institutional repositories have the potential to move beyond traditional publications to support new forms of research and research output exposure. The *DART* project is seeking to respond to this challenge by developing a comprehensive approach to managing information throughout the research life cycle (from lab book to formal outputs to teaching) in a range of interdisciplinary groups – climate change, environmental/water research, tropical and marine sciences; protein crystallography, history and social research. In the process, it will look at new forms and producers of raw data, new forms of collaborative research activity, new forms of publication and new forms of research validation.

### 5.16.2 Grid enabled technologies and infrastructure

Investment is needed to support the further development of grid technologies that enhance the capacity of e-research to provide researchers with pervasive and seamless access to high performance computing capabilities, large scale data collections, visualisation systems, sensors, instruments and technical support. Grid infrastructure is beginning to underpin the operation of dynamic, virtual organisations in research, government and business.

Collaborative access to resources needs to work at all levels, within and between research groups, and within and between institutions, nationally as well as internationally.

Middleware is a set of software and services designed to allow researchers to easily access these resources. To be effective, the middleware that supports collaborative access must conform to common standards, rely on a trust federation and, in many instances, use common software. While the general architecture of middleware has been defined for some time, considerable work is needed to tailor it to the specific requirements of individual research fields.

Work is underway on the issues of access, authentication and authorisation identity management. For example the *Meta Access Management System Project* (MAMS) is developing the software for creating better linkages between university information technology systems. *MAMS*, which is attracting international attention, is allowing researchers and students to access information more easily and seamlessly from different sources, both within and between universities.

### 5.16.3 Technical expertise

Investment is needed in the expertise and capability required to address the many technical challenges to be solved in developing enabling platforms and applying them effectively to the task of producing more collaborative and better research. In addition to the expertise required in the development and implementation phases, another significant issue is the skill sets required to support the researchers. Not every researcher can be a top-flight programmer, or a digital librarian, in addition to meeting the extensive demands of their own particular professional discipline. It is therefore important to develop and reward the new and emerging occupations that can provide the necessary technical expertise.

Computational science is one such emerging area. These people sit between the researchers and computer scientists to facilitate access, write the programs to support the research and link to other support personnel. Support services are a critical component of the necessary infrastructure.

In order to have the best chances of ensuring the highest quality content of research outputs at the earliest stage of the research process it may also be necessary to seed research teams with information management professionals. Such professionals can assist researchers with their information management needs and also develop guidelines, tools etc for particular disciplines or particular needs.

### 5.16.4 High performance computing

The demand for high performance computing systems with increased capacity and capabilities has been traditionally driven by the need to model and simulate complex natural systems and processes in, for example, chemistry, physics, biology, geology and the environment. There is now an increasing number of users/ researchers for whom access to large-scale data is an essential requirement of their research. They are often concerned with data processing techniques such as searching, filtering, comparing, mining and pattern discovery. These techniques arise in many scientific areas such as bioinformatics, astronomy and cryptography and have applications in fraud detection, risk assessment, market information, intelligence gathering and security.

Users/researchers now need access to powerful high performance computing capacity, mass data storage systems, interactive visualisation systems and high capacity communication services. They are requiring services such as grid computing and federated databases that make increasingly more extensive use of high performance computing facilities in a collaborative environment. Consequently the demand for high performance computing can be expected to maintain the exponential growth pattern of previous years. It is important that this growth occurs in a cost effective manner that is consistent with the requirements of the research grids that will be progressively established, and that the impetus established by Australian Government investments in high performance computing since 2000 is maintained.

### 5.16.5 High capacity communication networks

The presence of a robust communications network is fundamental to research endeavour. Most developed countries are investing in upgrading their national research and education networks. In recent years the Australian Government has invested more that $80 million in the Australian Research and Education network (AREN), a multiple gigabit per second optic fibre network connecting most university and research institutes within Australia and with substantial trans-Pacific connectivity.

The quantum of this investment has brought about a step change in the bandwidth of the network. There will need to be further modest level of investment to maintain and extend the network. Investments will be necessary, for example, to improve connections to more remote research activities and to substantially improve international connections to Asia and Europe.

#### 5.16.5.1 NCRIS Committee recommendations

The Committee plans to make recommendations to the Minister in the second quarter of 2006 as to how much NCRIS funding should be set aside for investment in the generic technological platforms needed to support research. In framing this advice, the Committee will be guided by needs emerging from the NCRIS investment proposals in specific capability areas, and input from the committees currently tasked with providing advice in this area.

# Appendix 1 - NCRIS Committee terms of reference and membership

## 1 Terms of reference

The NCRIS Committee will advise the Government on the ongoing implementation, monitoring and review of NCRIS. The Committee's specific responsibilities will include:

- advising the Government on national research infrastructure strategy and priorities, including:
- priority areas of research for major infrastructure investment within the scope of the NCRIS funding programme. The Committee will further develop the Strategic Roadmap, initiated by the interim NCRIS Advisory Committee, to give specific guidance on priority investment areas and implementation options;
- infrastructure requirements for the national research and innovation system outside the scope of the NCRIS funding program, including the development of 'landmark' facilities and support for basic and institutional level infrastructure;
- advising on the coordination of infrastructure funding decisions with research funding agencies, across government and across levels of government;
- advising on NCRIS funding allocation processes, including the development of program guidelines, and the implementation of NCRIS funded projects;
- advising the Government on progress in implementing NCRIS, including any barriers to effective implementation; and
- advising the Government in relation to the review of NCRIS funded projects and NCRIS in general.

## 2 Membership

Dr Mike Sargent (Chair)
Director, MA Sargent & Associates Pty Ltd

Dr Evan Arthur
Group Manager, Innovation and Research Systems, DEST

Professor David Beanland
Emeritus Professor, RMIT University

Dr Roger Lough
Chief Defence Scientist
(Expert Subcommittee Chair – Safeguarding Australia)

Dr Phil McFadden
Chief Scientist, Geoscience Australia
(Expert Subcommittee Chair – An Environmentally Sustainable Australia)

Professor Alan Pettigrew
Chief Executive Officer, National Health and Medical Research Council
(Expert Subcommittee Chair – Promoting and Maintaining Good Health)

Dr Leanna Read
Managing Director and CEO, TGR BioSciences Pty Ltd

Dr Stephen Walker
Executive Director, Engineering and Environmental Sciences, Australian Research Council
(Expert Subcommittee Chair – Frontier Technologies for Building and Transforming Australian Industries)

# Appendix 2 – Expert Advisory Arrangements

The NCRIS Committee was advised by four expert subcommittees tasked to advise and consult on infrastructure needs related to each of the four National Research Priorities. It was advised on e-research capabilities by the Government's e-Research Co-ordinating Committee, the Australian Research Information Infrastructure Committee (ARIIC) and the Australian Research and Education Network Advisory Committee (ARENAC).

The members of the four expert subcommittees were:

A/Professor Gary P Anderson
Department of Pharmacology
The University of Melbourne

Professor Tony Bacic
Director, Plant Cell Biology Research Centre
The University of Melbourne

Professor Judith Black
Department of Pharmacology
The University of Sydney

Dr Brian B Boyle
Director, Australian Telescope National Facility
CSIRO

Dr John Church
CSIRO Marine Research and Antarctic Climate and Ecosystems CRC

Dr George Collins
Chief of Research
Australian Nuclear Science and Technology Organisation

Dr Wendy Craik
Chief Executive
Murray-Darling Basin Commission

Professor Peter Cullen
University of Canberra

Professor Stuart Cunningham
Acting Dean, Creative Industries Faculty
Queensland University of Technology

Professor George Dracoulis
Department of Nuclear Physics, R.S.Phys.S.E
Australian National University

Professor Calum J. Drummond
Chief Research Scientist
CSIRO Molecular and Health Technologies

Dr Annabelle Duncan
Associate Director,
Bio 21

Professor Hugh Durrant-Whyte
Research Director
ARC Centre of Excellence for Autonomous Systems, ACFR

The University of Sydney
Professor Peter J. Fuller
NHMRC Senior Principal Research Fellow
Prince Henry's Institute of Medical Research

Dr Ian Fuss
Chief Scientist (Information)
Defence Science and Technology Organisation

Professor Helen Garnett
Vice-Chancellor
Charles Darwin University

Professor Andrew Gleadow
School of Earth Sciences
The University of Melbourne

Dr Bruce Godfrey
Principal, Wyld Group Pty Ltd

Dr TJ Higgins
CSIRO Plant Industry

Professor David J Hill
Cancer Council Victoria

Dr Robert Hobbs
formerly General Manager Research, BHP
& Foundation Chairman, CRC for MicroTechnology

Dr Barry Inglis
CEO and Chief Metrologist
National Measurement Institute

Professor Anthony F Jorm
ORYGEN Research Centre,
The University of Melbourne

Professor Max Lu
Director, ARC Centre for Functional Nanomaterials
The University of Queensland

Dr Mark Matthews
General Manager, Howard Partners
Visiting Fellow, Department of Engineering, Australian National University

Professor Tim McCormack
Asia Pacific Centre for Military Law
The University of Melbourne

Professor Caroline McMillen
Research Centre for the Early Origins of Adult Health
The University of Adelaide

Dr Steve Morton
Group Executive
CSIRO Environment and Natural Resources

Professor James A Piper
Professor of Physics and Deputy Vice-Chancellor (Research)
Macquarie University

Dr Ian Poiner
CEO
Australian Institute of Marine Science (AIMS)

Dr John Radcliffe
Commissioner
National Water Commission

Professor Tim Reeves
Principal, Timothy G. Reeves and Assoc. Pty. Ltd

Dr Mike Rickard
Post-retirement Fellow, CSIRO

Dr James Robertson
Manager of Forensics and Technical Services, AFP
Vice-Admiral David Shackleton

Shackleton Management Solutions (Chief of Navy Retd)
Mr David Templeman
Director-General, Emergency Management Agency

Professor Matt Trau
Centre for Nanotechnology and Biomaterials
The University of Queensland

Dr Graeme Woodrow
Chief, CSIRO Molecular and Health Technologies

# Appendix 3 – Development of the Strategic Roadmap

In November 2004 the NCRIS Advisory Committee released a discussion paper for public consultation proposing a set of principles and processes to underpin NCRIS. The paper also proposed that a Strategic Roadmap might be developed as a mechanism to advise government on priority areas for infrastructure investment and to assist in coordinating the development of major infrastructure. Stakeholders were invited to comment on the concept and an initial outline of potential priority capabilities.

Feedback on the Roadmap concept was positive. Most of the stakeholders who responded recognised the value of a planning document providing a strategic overview of Australia's infrastructure requirements and a focus for coordination of effort.

The Advisory Committee also received a significant number of submissions (from the total of around 80 submissions in response to the discussion paper) putting forward suggestions for priority areas that should be recognised in the Roadmap.

The Advisory Committee subsequently decided to scope potential areas of priority capability more completely. In May 2005 the Advisory Committee released a document (the *Capability Scoping Document*) that summarised the inputs to date and again sought feedback on gaps and omissions. A substantial and broad ranging response was received, which, together with the initial submissions, provided a large body of information on the infrastructure requirements of Australia's research systems and possible priorities within those requirements. An expert forum[12] was also organised to help scope the Roadmap and begin to provide a strategic overview of needs.

Following the work of the Advisory Committee, the NCRIS Committee ("the Committee"), when it convened and reviewed the outcomes of the early consultation processes undertaken by the Advisory Committee, recognised that while the range of potential capabilities had been widely scoped, the Roadmap process required more strategic insight and expert advice to gauge their relative fit with the NCRIS principles.

The Committee convened four expert subcommittees comprising a broadly representative group of researchers (see Appendix 2) to assess the information gathered to that point and advise on strategic direction. The subcommittees were

[12] The expert forum was held on 25 May 2005 in Canberra. Participants were invited from the Learned Academies, funding and research agencies and professional associations

organised to specifically examine the strategic requirements of each of the National Research Priorities against the advice received in consultations and submissions.

The Committee and its subcommittees also took into account the outcomes of other exercises such as the Pharmaceutical Industry Action Plan, the National Nanotechnology Strategy, the Marine Science Action Plan, the Decadal Review of Australian Astronomy and the National Strategic Plan for the Geosciences. In addition the Committee consulted with the e-Research Coordinating Committee, the Australian Research Information Infrastructure Committee (ARIIC) and the Australian Research and Education Network Advisory Committee (ARENAC). Finally, a State and Territory Government official's reference group, chaired by Dr Mike Sargent, was formed to provide a conduit for information and advice between the NCRIS Committee and state and territory governments.

The work of the Committee and its expert subcommittees culminated in November 2005 with the publication of a first draft ("Exposure Draft") of the Strategic Roadmap, outlining a set of priority capabilities which the Committee had identified as having compelling arguments for investment support. The Exposure Draft was made available for public consideration and comment, and feedback was invited on both the broad scope of the document as well as specific issues (including infrastructure and support requirements relating to the capabilities outlined in the document) identified by the Committee that would benefit from further exploration. It was also the subject of a further round of targeted consultations across the States and Territories.

The final Roadmap reflects the feedback received through this consultation process.