Australian Government

Department of Innovation, Industry, Science and Research

Strategic Roadmap for Australian Research Infrastructure

AUGUST 2008

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Figures

Executive Summary

Over the past four years, a major change has taken place in the way that Australia plans and prioritises investment in research infrastructure.

A new mode of investment has emerged that recognises the need to deliver infrastructure that supports priority research areas and is available to researchers across Australia.

This new approach is strategic in nature, encourages a collaborative approach, and provides Australia with the national research facilities and linkages needed to address the economic, social and environmental challenges of the 21st century.

Australia's approach to infrastructure investment draws together organisations in the higher education, government, non-profit and business sectors. These linkages ensure that research outcomes are translated into tangible national benefit such as increased productivity and the development of new products by business, and the improved management of health, environment and security issues by government.

The National Collaborative Research Infrastructure Strategy (NCRIS) has been a catalyst for this change. This significant investment in infrastructure funding has been based on new ways of thinking about how Australia can plan and invest in facilities and networks that support world class research across the innovation system.

Australia's approach has been adopted and is being implemented by a range of nations now engaged in strategic planning to address and fund research infrastructure priorities at the national and international level.

This strategic, collaborative approach to investment has been largely embraced and supported by the research community, and provides a starting point for future research infrastructure programs. It has demonstrated that:

- The development of national infrastructure networks can support research that addresses issues of national significance such as climate change and emerging diseases;
- Implementing national access regimes for research facilities can increase use and stimulate cross and multi-disciplinary research;
- Coordinated acquisition of leading edge instruments in areas such as microscopy, imaging and bioplatforms can achieve substantial economies of scale and enable partnerships with industry to be established;
- Coordinated investment encourages institutions to work together and enhance the ways they collaborate. A key enabler for these approaches is the use of information and communications technology (ICT);
- Research services and networks enable the linking of researchers, data, facilities and technical expertise, which in turn facilitates new and enhanced research outcomes; and
- Collaboration helps to translate research outcomes into national benefit.

A key element of the NCRIS program was the development of a Strategic Roadmap released in 2006. The 2006 Roadmap, which identified 16 priority areas for investment in research infrastructure, was developed following an extensive consultation process with the research community and other stakeholders. The funds available in the NCRIS program were sufficient to implement 12 of the priority capabilities.

Following a structured process of consultation with stakeholders, this Strategic Roadmap for Australian Research Infrastructure builds on the 2006 Roadmap, and presents a renewed view of where strategic infrastructure investments should be made over the next five to 10 years.

Scope of this Roadmap

Research infrastructure can range from institutional or local level investments in an individual piece of equipment through to landmark infrastructure investments with long time frames and major national and international impact.

While smaller infrastructure investments can be pursued by a single institution or partnership, larger investments with national implications benefit from a more strategic and collaborative approach.

This Roadmap focuses primarily on describing Australia's major national and systemic infrastructure investment priorities and on arrangements for the assessment and implementation of landmark infrastructure projects.

Priority Capabilities

This Roadmap reaffirms that the 12 capabilities progressed from the 2006 Roadmap continue to represent priority areas for investment.

Increased emphasis is placed on eResearch in recognition of the pervasive and underpinning relevance of ICT to research. As collaborative research increases, eResearch is providing the most influential and effective way of enabling institutions to work together, using shared infrastructure, resources and policies.

A new capability in the Humanities, Arts and Social Sciences (HASS) has been identified in recognition of the wide ranging contributions these disciplines make to the national interest. Investment in this area would relate to a HASS eResearch infrastructure including data creation and digitisation of research materials.

Insufficient funds were available in the NCRIS program to progress four areas from the 2006 Roadmap. With regard to these areas, this updated Roadmap:

» Reaffirms the need for investment in Translating Health Discovery into Clinical Application;

» Supports investment in a redefined capability relating to Disaster and Hazard Testbeds; and

» Supports further scoping of investment needs relating to A Sustainable Energy Future and Heavy Ion Accelerators.

In addition, this Roadmap has identified a need for investment in research infrastructure relating to the Built Environment.

Going forward

Whilst this new approach to planning and investing in research infrastructure is still evolving, the shift that has taken place towards strategic investment in priority areas means Australia is well placed to build on recent research infrastructure developments.

There is strong stakeholder support for a collaborative approach to research infrastructure investment. However, lessons learned from the NCRIS program provide a basis for improving the design and execution of future collaborative investments.

This Strategic Roadmap for Australian Research Infrastructure indicates that a continued and considerable investment is required in research infrastructure to capitalise on the strategic planning process and investments made to date while also developing new capacity.

Subject to the availability of further funding, the implementation of this Roadmap will involve consultation with the research community and other stakeholders to agree the detailed needs for each capability area. The feedback and responses that were provided by these groups in developing this Roadmap will be valuable in informing this process.

With respect to landmark infrastructure, a structured planning process is needed to enable more efficient and informed decision making for investments of this magnitude.

Future review and updating of this Roadmap is required at strategic intervals, to reflect changing priorities and emerging areas of focus, and in particular to maintain relevance within a global context.

1. Introduction

Following the announcement by the Australian Government of over $500 million in funding for the National Collaborative Research Infrastructure Strategy (NCRIS), extensive consultation was undertaken with the research community, funding providers, industry and government agencies at state, territory and federal level to develop a Strategic Roadmap for Australia's medium-to-large research infrastructure requirements over the next decade. That Roadmap was released in 2006.

Through the NCRIS program, implementation of the 2006 Roadmap is underway, with investments made in a range of priority research capability areas including biomolecular platforms, characterisation, the marine observing system, information and communications technology, and astronomy. Outcomes such as the establishment of collaborative infrastructure networks that support research in areas of national significance, provision of access for researchers to national networks of instrumentation and expertise, and the enabling of research collaboration across jurisdictions and institutions, are already being achieved from these investments.

Two years on from the release of the 2006 Roadmap, a high-level consultative review of the research capabilities and infrastructure requirements has been undertaken to reflect on and refresh the strategic view of Australia's needs going forward. The result of this review is this document – the Strategic Roadmap for Australian Research Infrastructure – which builds on the 2006 Roadmap and provides an overview of where enhanced and ongoing development of our research capabilities should be focused over the next five to ten years. This Roadmap will inform decisions around the future investments necessary to deliver these capabilities.

2. Strategic Direction for Australia's Research Infrastructure

The role and nature of research infrastructure

Importance of research

The Australian Government is committed to supporting research and its role in the discovery of ideas, solving problems, and enabling new applications and technologies. Research undertaken in universities, publicly funded and not-for-profit research agencies, state and territory government agencies, and industry contributes to the knowledge economy, to boosting our innovation performance and enabling Australia to compete at a global level. Research as a contributor to innovation needs to be appropriately resourced, whether this is in relation to the research activity itself, the research skills or the research infrastructure. In helping address national challenges and increasingly global science and social questions, researchers require an environment that encourages and enables creativity in their work and in the way their work takes effect.

Research infrastructure is a vital resource

Investment in research infrastructure is an essential input to the conduct of excellent research. Research infrastructure is a vital subset of the resources that support researchers. It comprises the assets, facilities and services that support organised research and development across the innovation cycle and that maintain the capacity of researchers to undertake organised research[1]. In this sense, research infrastructure includes more than just physical assets, and extends to enabling infrastructure such as information and communication technologies (ICT) and skilled support staff who maintain and operate research facilities.

Some infrastructure investments involve providing Australian researchers with access to major research facilities located overseas. International collaboration of this sort helps to link Australian researchers more strongly with the global research community. Correspondingly, investments in national research infrastructure can contribute to building world class facilities that are attractive to overseas researchers.

Categories of research infrastructure

Categories of research infrastructure can be represented in many ways. One useful view of this is illustrated on the next page, and denotes research infrastructure by the quantum of funding required and the impact on the national research agenda. In addressing the needs of each of these categories, consideration must be given to how they interact and contribute to a coordinated approach, while continuing to recognise the autonomy of the categories. It is also recognised that no single process can satisfy requirements across the continuum of research and that appropriate mechanisms are needed for different situations.

At the institutional level, investments in research infrastructure are generally site-specific in nature and are implemented from the host institution's resources. The Research Infrastructure Block Grants (RIBG) program is a key funding mechanism for universities in this respect.

1 The Final Report of the National Research Infrastructure Taskforce, 2004.

At the project level, institutions may collaborate on a single initiative which is implemented in a coordinated fashion. This allows for the development of larger scale initiatives that may not be possible at the institutional level. Programs such as the Australian Research Council (ARC) Linkage Infrastructure and Equipment Fund (LIEF) and the National Health and Medical Research Council (NHMRC) Enabling and Equipments Grant support this category of research infrastructure.

Moving from medium through to large research infrastructure, initiatives are characterised by their collaborative, systemic, or landmark nature and often have an international dimension. This Roadmap focuses on *Integrated National Facilities* and *Systemic or Strategic Infrastructure*. Comment is also made in this Roadmap about *Landmark Infrastructure* needs.

It must also be recognised that infrastructure is often not exclusively research focused. In many areas the infrastructure can be used in a complementary function for other purposes, such as operational uses and applications. Clear examples of this are the analytical laboratories associated with forensics and hazard identification, pilot manufacturing plants for short run production and some specialised teaching facilities. Thus in many cases such capabilities can be resourced, in full or in part, by funding from other than research infrastructure sources (for example, industry grants). It is an important aspect of this Roadmap that this complementary nature of research infrastructure be identified so that the appropriate leverage is taken into account.

Collaboration is increasingly important

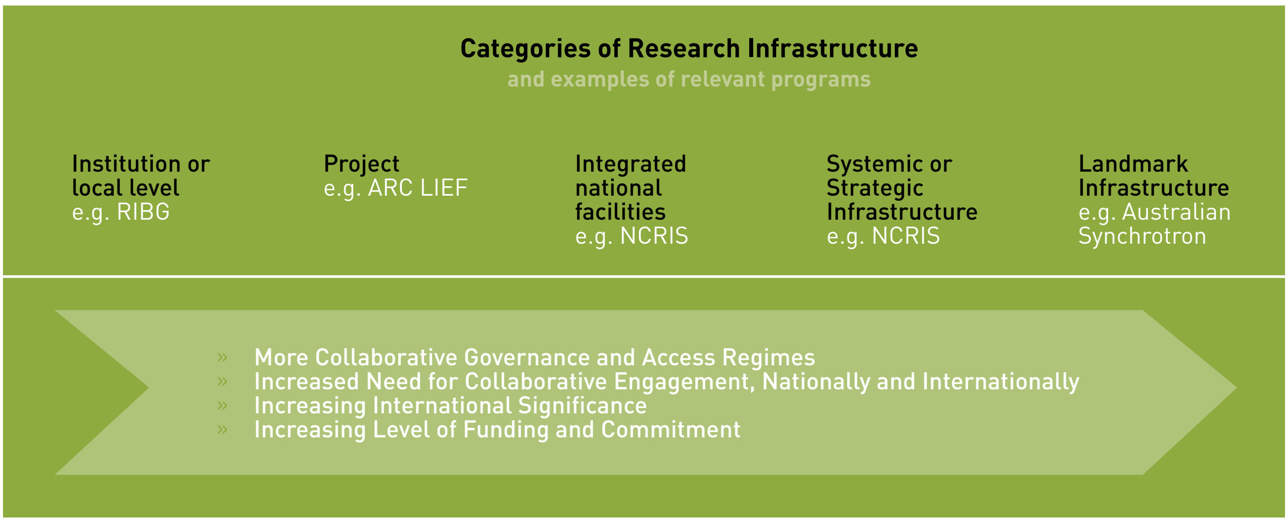
There is increasing acceptance - in the context of high demand but limited resources - that collaborative approaches have a key role to play in contributing to the delivery of research outcomes. It is becoming clear that bringing researchers together, across institutional, disciplinary and geographical boundaries - both national and international - generates new and particular opportunities for science and social breakthroughs through access to a greater collective intellectual capital.

Collaborative research infrastructure

There are economic and efficiency arguments for taking collaborative approaches to establishing research infrastructure that enables world-class research. In the main, single institutions on their own cannot achieve the levels of research infrastructure needed to support such research. Economically, it makes sense for universities, state, territory and federal governments, non-profit research institutes and business to cooperate in implementing these research infrastructure investments.

Efficiency gains reside not only in avoiding duplication in the creation of the infrastructure, but also in optimising its use, such that a piece of research infrastructure can be used to its maximum available capacity. To promote this greater use of the infrastructure, access regimes should provide for infrastructure to be broadly available to researchers across Australia. An added benefit of the collaborative environment created by joint investment and development of the infrastructure is that it encourages the host institution to implement such open access regimes.

Figure A



Collaborative research infrastructure can support research that is relevant and competitive in the global research marketplace by providing the improved analytical and predictive power needed to meet major challenges. Many issues, for example climate change and the transmission of emerging plant, animal and human diseases across borders, cannot be addressed effectively in a piecemeal or segregated way and demand engagement and cooperation between researchers. Collaborative research infrastructure is proving integral to enabling and fostering approaches to such cross-disciplinary and national issues.

The nature of collaboration, which enables focused linkages with business and government policy and operational agencies, ensures that research outcomes translate into national benefit for society. For example, a collaborative approach to providing research infrastructure ensures that relationships are in place with the government agencies that will use the research to achieve improved management of health and environment issues, and with the businesses that will develop and market new products such as therapeutic goods or energy saving devices.

Strategic planning becomes possible

International experience suggests that a collaborative approach to investment planning both enables and demands a strategic plan of priority investment areas to be developed. Such an approach enables universities, governments, non-profit research institutes and business to cooperate in targeting and implementing those research infrastructure investments that will support priority research areas, provide the greatest return for the nation and support world-class initiatives.

The NCRIS program

A new research infrastructure approach

In 2004, in response to the report of the National Research Infrastructure Taskforce (NRIT) and acknowledging the need to bring more strategic direction to Australia's investment in research infrastructure, Australian Government funding of $542 million over seven years was allocated to the National Collaborative Research Infrastructure Strategy (NCRIS).

The objectives of the NCRIS program are to:

» Provide major research infrastructure that is national, strategic, collaborative and world-class;

» Promote a sustained cultural shift towards investment attitudes that are national, strategic and collaborative; and

» Foster research activity that is collaborative and world-class.

An Advisory Committee was appointed to advise the Government on the implementation of the NCRIS program. The key principles underpinning NCRIS reflect the Advisory Committee's advice and are as follows:

» 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 focused 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.

Based on these principles, the 2006 Roadmap was developed by the NCRIS Committee following extensive consultation with the research community and other stakeholders. The purpose of the 2006 Roadmap was to inform decisions on where Australia should make strategic infrastructure investments to further develop its research capacity over the next 10 years.

Basis for continued approach

The implementation of the 2006 Roadmap under the NCRIS program has been broadly accepted locally and internationally as an effective way to plan for and implement research infrastructure.

The NCRIS program brings together researchers, institutions, governments and business to discuss strategic, national research priorities and the infrastructure that will be needed to support that research. This creates an environment where groupings of innovative people with relevant knowledge, skills and tools are in frequent contact about emerging issues. Outcomes are already being achieved from these investments such as:

- The establishment of collaborative infrastructure networks that support research in areas of national significance;
- Provision of access for researchers to national networks of instrumentation and expertise;
- The enabling of research collaboration across jurisdictions and institutions;
- Cost savings in the acquisition of infrastructure; and
- Improved links with industry and government agencies.

Recognising the importance of the infrastructure to the research community, NCRIS investments are attracting substantial co-investment from state and territory governments. The intersection between these interests can create exciting and fruitful collaborations that benefit researchers across jurisdictions.

3. Strategic Roadmap for Australian Research Infrastructure

In the light of changing priorities and new opportunities, a high-level consultative review of the 2006 Roadmap has been undertaken to reflect on and refresh the strategic view of Australia's needs in going forward. A focus of the review was to refine and update the capabilities identified in the 2006 Roadmap and identify new capabilities where appropriate. Details of the review process are at **Appendix A**.

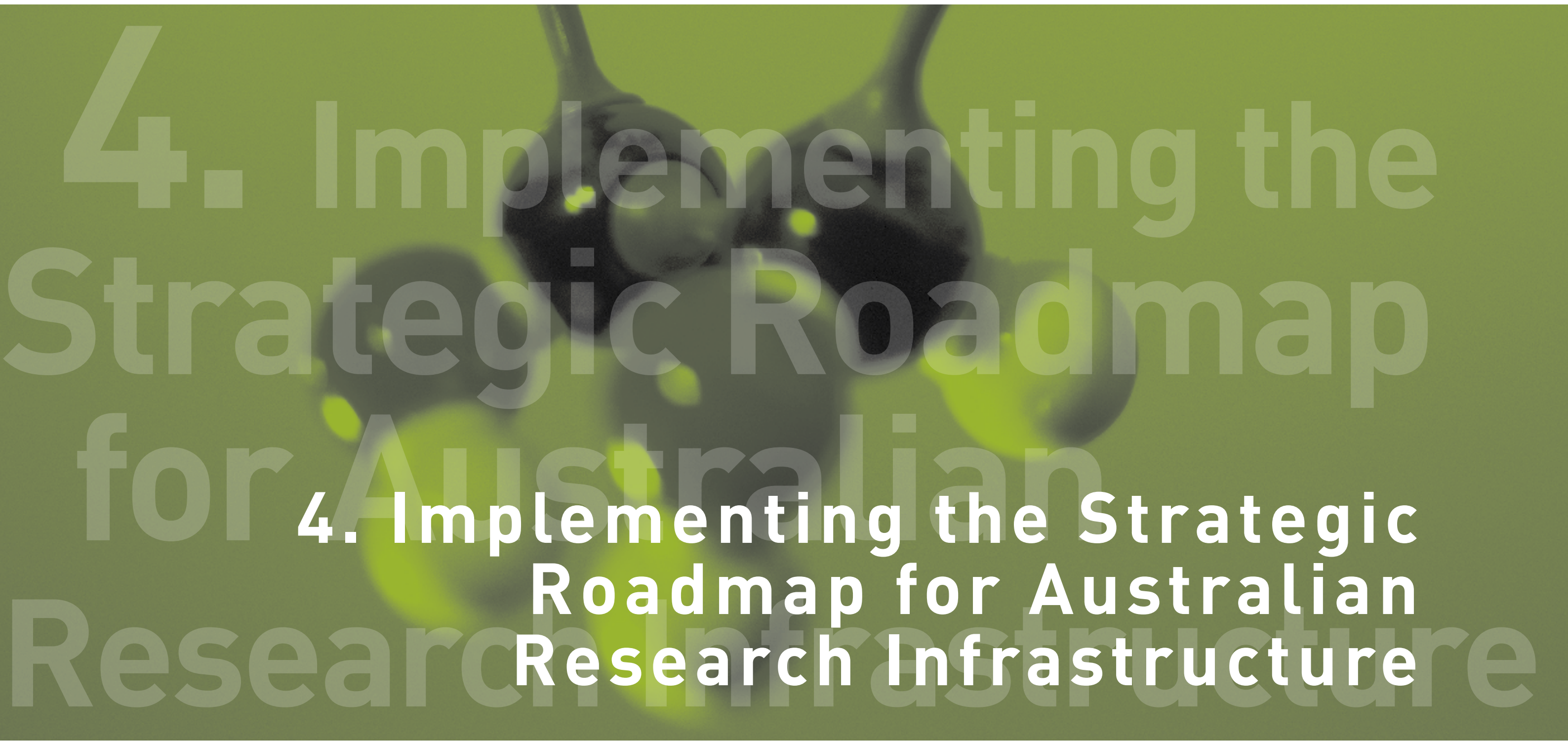
The outcome of the review is this document, the Strategic Roadmap for Australian Research Infrastructure.

This Roadmap will inform the Australian Government's decisions on future strategic research infrastructure investments. It builds on the 2006 Roadmap and its implementation as well as incorporating new, unaddressed or previously unidentified areas. There has been a focus on the strategic impact of each capability, taking into account existing collaboration and the international context. Efforts have been made in this Roadmap to better articulate the challenges and assumptions that underpin and drive each capability.

Key findings

Based on the consultation undertaken and input provided by stakeholders, key findings include:

- The capabilities identified in the 2006 Roadmap are supported as appropriate and continue to be priorities.
- A number of additional needs identified across key areas result in a reshaping and, in the most part, a supplementing of elements in individual capabilities.
- Humanities, Arts and Social Science are specifically recognised as an important capability area, in view of this research area's significant contributions to national outcomes.
- The significance of information and communication technologies as an underpinning and pervasive capability is strongly acknowledged.
- The inclusion of data itself as collaborative research infrastructure is highlighted.
- The grouping in this Roadmap of related priority areas further recognises and emphasises the linkages between specific capabilities (see **Section 6**).
- A range of challenges, enablers and considerations (see **Appendix B**) were brought to light during the review that are relevant to the efficient and effective conduct of a collaborative infrastructure program.



4. Implementing the Strategic Roadmap for Australian Research Infrastructure

Established arrangements continue

The implementation of the 2006 Roadmap is currently occurring, with the available NCRIS program funds enabling 12 priority capabilities to be implemented. The approach of developing detailed investment plans through a facilitation process for each of the capabilities, during which the relevant research community, institutions and funding providers cooperatively identified specific infrastructure for investment, has been generally well accepted by stakeholders and internationally recognised as an exemplar. A summary of the capabilities being implemented is at **Appendix C**.

The development of the Strategic Roadmap for Australian Research Infrastructure has occurred at a period when future funding decisions are under consideration. The implementation of this Roadmap will build on the existing arrangements when further funding becomes available. While existing capabilities have been re-grouped and linked with others in this Roadmap, the research community's further input will be taken into account when considering the structural arrangements that are most appropriate to developing these capabilities.

Going forward

The next step will involve a process to agree the detail of how this Roadmap will be implemented. This process will continue to place emphasis on collaboration and consultation. The feedback and responses provided by the research community and key stakeholders during the development of this Roadmap will be valuable in informing this process.

Concomitant with seeking further funding will be the sustaining of a collaborative and strategic approach to the planning and investment in research infrastructure which has been established through the NCRIS program.

The gains made from implementation of established capabilities will be recognised and built on. Lessons to date will help inform the implementation of new areas or capabilities under consideration.

Lessons for future program implementation

The NCRIS program has been an unprecedented approach to planning and investing in research infrastructure. Implementing this novel and strategic approach to research infrastructure has highlighted a number of lessons that may guide future programs. These lessons support the approaches that NCRIS has taken but also recognise aspects for further refinement and expansion.

i. Enabling infrastructure is integral and requires specific consideration

Experience from the implementation of the 2006 Roadmap has shown that some elements are common to all or most capabilities, and must be present and well-resourced for the capabilities to advance. These elements apply generically in the way they enable the development of capabilities and include: information and communications technology (ICT); skills and expertise; and governance and management models to drive and direct the implementation of a capability. These elements are further discussed in the box next page.

ii. Continued cultural change is needed to optimise benefits

Feedback suggests that road-mapping and facilitation processes have contributed to the gradual development of a more collaborative culture among institutions and researchers. While the development of a national, collaborative culture is still evolving, highlighting the collaborative structures or mechanisms already in place as a basis for implementation of capabilities is important.

iii. The need to acknowledge emerging areas of strategic importance and smaller players

During implementation, the need to ensure that the infrastructure requirements of emerging areas of strategic importance are adequately taken into account became evident. It is also important to ensure that the needs of smaller players working in strategically important areas are considered, while retaining the emphasis on collaboration and the realisation of economies of scale wherever possible.

iv. Open access models encourage uptake

To promote greater use of the infrastructure, access regimes that provide for infrastructure to be broadly available to researchers across Australia were found to be necessary. This includes access by government, non-profit and private sector researchers. Access and pricing models should continue to provide access to the funded research infrastructure for publicly funded researchers, including regional users and researchers in small institutions, at marginal cost on the basis of merit. An added benefit of the collaborative environment created by joint investment and development of the infrastructure is that it encourages the host institution to implement such open access regimes.

v. Cross-capability linkages are vital

Linkages between capabilities can be facilitated through: collaborative approaches to planning and developing investments that build relationships; researchers' improved access to each other and facilities, including collections; and the support for research collaboration and projects. The dominating and essential element to support such linkages is ICT, in particular the collaborative tools, networks, and mechanisms to facilitate the sharing of data.

It is recognised that some capabilities – as a result of the community's demand, historical use or urgent need – take a lead in establishing and operating specific research infrastructure that has wider application. For example, remote sensing has a strong user and operational base in marine and geosciences, but the need for it is also common to other capabilities. Access to spatial information is a similarly common need across capabilities. Supporting the development of such infrastructure by the lead capability – in coordination with other relevant capabilities – can have broader benefit.

The co-location of facilities and expertise in existing or emerging research and industry precincts can capitalise on current investments and enable integration across capabilities. It also has potential to provide additional synergies amongst research groups from different disciplines and economies of scale. Significant benefit can be achieved in areas, such as nanotechnology and biotechnology, where co-location can support integrated approaches to research.

Collections, such as biological, social and cultural, represent important sources of information for research purposes across many capabilities. For example, biological collections have relevance to medical research as well as environmental studies and biosecurity. Equally, social data collections underpin research in social sciences and fields such as response to natural hazards. The infrastructure required to support researchers' use of these collections includes the platforms necessary to retain, manage and provide access to these collections and involves the participation of providers such as libraries and museums, in addition to universities and other research organisations.

Enabling Infrastructure

Research infrastructure includes more than just physical assets and extends to elements that are needed to maintain and operate the research facilities in a way that enhances access and facilitates cross-disciplinary projects. In broad terms, these can be considered as "enablers" that underpin and are vital to the overall delivery of research outcomes.

Skills and Expertise

Skills and technical support skills are integral to the effectiveness of research infrastructure. Technical expertise - in the use of infrastructure and information and communications technology - is necessary for advanced, novel ways of researching. Researchers benefit from having a skilled understanding of the implications and role of infrastructure in that it helps them not only adopt but create new forms of research. In Australia, there is a recognised difficulty in accessing appropriately skilled people, and this is supported by evidence and articulation of needs across the capabilities. In some cases, the expertise needed is rare and exists within only one or two capabilities.

Investment in research infrastructure must therefore be supported by the appropriate development of relevant research skills and technical support skills. In addition, the absence of dedicated career paths and remuneration commensurate with the importance of these skilled personnel must be addressed. An added complexity is that, as the use of research infrastructure increases and as research becomes more collaborative and shared, the demands for and on these expert or skilled personnel intensify.

Information and Communications Technology

The availability of appropriate information and communications technology infrastructure has an important role to play in supporting research in all fields. This use of ICT to support research is referred to as eResearch. eResearch is essential because:

(a) It facilitates more effective research collaboration at any scale;

(b) Collaborations are growing in size and diversity; traditional means for collaboration do not scale and ICT is providing new means to respond;

(c) It provides a way for institutions to collaborate through shared infrastructure, resources and policies; and

(d) It enhances the effectiveness, efficiency and scope of research.

Specific ICT infrastructure requirements and benefits are further expanded upon under the eResearch Infrastructure capability.

Governance and Management

Just as skilled technical support is integral to the effectiveness of research infrastructure, so too is the 'governance and management' infrastructure that can provide strategic guidance, facilitate collaborative approaches to infrastructure investment, and coordinate the establishment of and access to infrastructure. This can also facilitate intra-capability and cross-capability linkages.

It is important to recognise that different approaches to implementation might be appropriate in different cases. A number of governance arrangements are currently in place under the NCRIS program. These vary in form and complexity, recognising collaborative mechanisms already in place and the difference in circumstances surrounding the development of each capability.

5. Landmark Infrastructure

This Roadmap does not address landmark infrastructure needs in detail. However, a number of specific landmark infrastructure requirements were identified during consultation with stakeholders.

In considering Australia's research infrastructure requirements, landmark infrastructure warrants special consideration because investments in this category have major national implications. For example, a platform for blue-water research is essential if Australia is to have the capacity to undertake world-class marine science and participate in international programs.

As a guide, the National Research Infrastructure Taskforce (NRIT) noted that Australian Landmark Facilities were typically large-scale, complex facilities that served large and diverse user communities, were generally regarded as part of the global research capability, and engaged national and international collaborators in investment and in access protocols[2]. Such facilities normally involve significant funding for the design and development phase, very large capital expenditure for the construction phase and significant ongoing operating costs.

There is currently no program, or process, that addresses landmark infrastructure investment. The introduction of a structured process to address possible landmark infrastructure projects would enable more efficient and informed decision making on these matters. Integration and coordination of landmark investments with the strategic planning of research infrastructure would provide consistent and cohesive outcomes. Such a process would entail the identification and assessment of landmark infrastructure requirements and would provide a structured pathway to developing investment plans for these projects of national and international significance.

2 The Final Report of the National Research Infrastructure Taskforce 2004, p.63.

6. Capability areas

The 2006 Roadmap identified priority capabilities with strategic significance for Australia. In the main, the emphasis in developing the capabilities was on integration of distributed capacity and expertise as well as addressing key gaps in order to build critical mass in infrastructure supporting the priority research areas. Research networks[3] in various forms have emerged as a core capability enabler and testify to the importance of and dependence on essential information and communications technology infrastructure. Having established a level of cohesion within capabilities with the implementation of the 2006 Roadmap, it became clear that far greater cross-capability interaction was feasible and desirable.

The Strategic Roadmap for Australian Research Infrastructure deliberately groups the priority capabilities with a view to further driving cross-capability collaboration. In some cases, there were already clear linkages between capabilities, for example those with an environmental or health context. In others, sub-components have been shifted between capabilities to reflect intuitive or existing associations:

- » Animal models of disease, previously part of an 'Integrated Biological Systems' capability, are now incorporated with biomolecular platforms, bioinformatics and high throughput screening of small molecules within an 'Integrated Biological Discovery' capability.
- » Plant phenomics and biological collections, also formerly part of the 'Integrated Biological Systems' capability, are incorporated within the 'Terrestrial Ecosystems' capability.
- » The manufacture of recombinant proteins and human cells, previously part of the 'Biotechnology Products' capability, are incorporated within the 'Translating Health Discovery into Clinical Applications' capability.
- » Biofuels, also previously part of the 'Biotechnology Products' capability, are incorporated into a 'Sustainable Energy Future' capability.

This has resulted in some reshaping that may not necessarily be manifested by co-location or amalgamation in the implementation phase but rather serves to emphasise the linkages between complementary areas. It also ensures a consistent and cohesive definition and description of infrastructure requirements. Six capability areas have emerged as a result that essentially incorporate the former priority capabilities (albeit with enhancements, additions and significant reworking of some) together with a new capability recognising the important and pervasive influences of the Humanities, Arts and Social Sciences.

3 Research networks in this context refer to connected and distributed resources and facilities.

eResearch Infrastructure

There is growing recognition that new ways to conduct research have emerged and are being validated across most research disciplines. Adding to traditional forms of research that rely on experiment, theory and testing hypotheses using data, it is now evident that researchers also:

» collect increasingly larger sets of data as a primary form of research; and

» use modelling tools to assist them in deriving patterns, perceptions and trends that can form the basis for establishing and confirming hypotheses.

Information and communications technology (ICT) is the cornerstone to such new approaches, providing the means not only for increasingly powerful computer-enabled simulation and modelling, but also the very avenue to manage and integrate the increasing volume and complexity of datasets and collections. Hence, ICT is not only a resource to administer and manage research but also to drive and innovate the ways in which research is conducted.

Contextual framework

Much of the research carried out around the globe is now conducted with the assistance of ICT tools and services.

Researchers can now reach out to each other from opposite ends of the country, even the globe, sharing data, ideas and instruments or equipment. Entirely new fields of research are emerging as researchers can now collect, move and manipulate large amounts of data, enabling new and much more complex problems to be addressed. The technologies themselves create new avenues through which research can be achieved; research is routinely undertaken that would be infeasible using any other means.

Such new and collaborative approaches to research, within disciplines and across disciplines and supported by ICT, constitute eResearch.

Defining eResearch Infrastructure as an enabling capability responds to a widespread debate on how ICT can support Australian research and empower national and international research collaborations. The debate is partly an outcome of the investments into the NCRIS Platforms for Collaboration (PfC) capability, through which NCRIS provides ICT support for research.

Description

As research is being redefined by ICT, it is vital that Australian researchers and research institutions have access to the infrastructure they need to participate in this transformation. The NCRIS Platforms for Collaboration (PfC) capability created a basis for this support by focusing on: collaboration tools; a national approach to data services; high performance computing; high performance networks; and access and authentication frameworks.

However, the scale of demand for ICT infrastructure for research, and the breadth and magnitude of the task to facilitate eResearch, are continuously increasing. Research communities are being challenged by this increasing dependence on ICT and the new abilities it brings to research in complex tasks and multi-disciplinary groups. A particular example of how this reliance has grown is the greater appreciation for the role of research networks in enabling research (such as the Australian Biosecurity Intelligence Network and potential networks in indigenous knowledge and culture described on page 42).

This growth translates into greater need but also different needs. It is not simply that more researchers need to keep, organise, manage and analyse data better and on a larger scale, or more often use models as a basis of their research, or more frequently seek better means to collaborate around shared data and associated tools. These needs in themselves are significant and affect the scope of the investment in eResearch. It is also that, as opportunities and different ways of using ICT emerge, and as researchers appreciate the potential of eResearch, new or more clearly defined needs reach a critical level. For instance, remote access to shared and unique collections and resources, including for regional or smaller institutional researchers or researchers in the field, is now critical.

Each of the capabilities in this Roadmap highlights the increasing need for infrastructure to meet the range of requirements described above. In expanding eResearch capacity to meet this growing demand, it is useful to conceptualise the proposed capacity in the following three categories:

» Infrastructure that enables new research and new forms of research, including high performance communications networks, high performance computing facilities, data storage, and resource access and authentication systems.

  The impact on researchers is not only that they can work with people at the far ends of the earth as easily as the person down the corridor or in the same room, but also that they can in the widest sense of the word visualise data and models of data, and interact with a wider community of ideas, in ways that add new perspectives and value to their research. Underpinning this sharing, the ability to store and secure research data such that its value and origin is always respected and recognised is a critical benefit that needs to be realised;

- Infrastructure that helps effect the transition from research to eResearch, including data federation and collaboration, such that researchers are able to work more effectively and easily with each other and in ways they had not previously imagined.

  Researchers will be able to participate in real-time in complex research endeavours that amass the collective knowledge, most recent analysis, and the latest facilities of peers in other institutions or locations. They will also be able to manipulate equipment or datasets or virtual representations of these on-site or from a distance – often in ways that would not otherwise be possible, such as with delicate documents or specimens; and

- Improved governance and expertise to ensure that personnel with the necessary skills and experience are available to drive and deliver these services and tools.

  As the increasing importance of ICT is recognised and as researchers become more accustomed to eResearch support, leadership in promoting, guiding, funding and using ICT will be necessary as will increasing the awareness and understanding of researchers of the potential impacts of these tools on their work.

Strategic Impact

Today's research challenges are complex and global, including problems such as climate change, sustaining ecologies and the environment, predicting and living with extreme geological activity, managing disaster reduction and security, improving the health of our population and containing infectious disease. Such problems demand profound understanding of complex systems that cannot be achieved by isolated efforts or real world experimental means alone.

The impact of eResearch is often most keenly apparent when a problem falls into this category of complexity or breadth and cannot be handled by a single institution, discipline or jurisdiction. Hence, researchers dealing with complex issues of health, biosecurity, terrestrial ecosystems and others benefit strongly from the use of ICT to bring together otherwise isolated or individual expertise, knowledge and analysis to bear on the problem. A key example of using ICT to leverage such linkages between disciplines is demonstrated by the case of PARADISEC on page 42.

On a different level, access to an up-to-date research network that connects researchers in real-time can bring significant benefit to addressing matters of high priority or immediate need (such as water management or disaster preparedness). High performance computing (HPC) resources that enable virtual experiments are sometimes the only way theory can be developed and tested. Finally, ICT can enable researchers' use of resources that present physical challenges in accessing them because they are otherwise too expensive, large, distant or fragile to be readily available. This latter impact includes for example researchers' access to the Australian Synchrotron or digitised archaeological collections.

Figure B

Hence the goal of this capability is multi-dimensional: to build a national foundation of eResearch capability that empowers research; and to enable researchers to accomplish studies of national significance which are beyond the scope of individuals and organisations. This aligns with both the UK e-science program and the US cyber-infrastructure initiative which have shown that an effective transition is best effected at the national level.

Challenges and Assumptions

Work underway on the Australian Research Collaboration Service (ARCS) and the Australian National Data Service (ANDS) will form a critical basis for addressing the future infrastructure and practices needed to collaborate and, in particular, to share, reuse and curate data. Similarly, work on the Australian Access Federation (AAF) in establishing trust between organisations and between researchers, and investment in high performance computing and high performance networks will be built on in further developing the eResearch infrastructure.

Transitioning from research to eResearch is challenging to researchers and research organisations. Research is traditionally competitive and researchers have limited capacity to share, in the sense that their funders, institutions and disciplines may have structures or mechanisms in place that impede the levels of collaboration needed to advance research. Institutions are also often unable to provide the level of general and discipline-specific ICT support to meet research needs. As an example, network performance can be throttled by institutional firewalls and enterprise networks. While high bandwidth pipes exist to the front gate, the small pipes with taps, filters and sometimes meters past that gate compromise usability and connectivity from a research and collaboration perspective.

Another challenge in developing eResearch Infrastructure is to ensure it can engage other investments and capabilities in a way that meets their needs and brings about highly developed solutions. The success of eResearch depends on the sustainability of resources available to identify and provide for the ICT requirements of researchers in those capabilities. Hence, an underlying assumption in developing a strategy for eResearch is that a long-term commitment will be made to the initiatives.

In addition, the increasing dependence on ICT expertise is presenting a particular challenge of its own – how to source the skills into the research sector and how to retain them. The pervasiveness of ICT adds a unique dimension to the issue of eResearch support.

Finally, while some researchers advance readily into an ICT-enabled world, it is important to assist other researchers. Action is needed to ensure that researchers, and the institutions that support them, better appreciate the benefits and imperatives of enabling research using ICT.

Requirements

Infrastructure

Enabling Components provide the infrastructure landscape that is essential and pervasive: resource access and authentication systems, data storage, a range of high performance computing facilities, and high performance communications networks.

- Access Management: to allow organisations to reliably and easily grant access to resources given a researcher's identity, and limit access or use of resources to those for which a researcher has been given permission. This component will build on the work of the AAF, which is developing and deploying the core components of such an infrastructure to facilitate collaborations locally, nationally and internationally. The AAF provides a Public Key Infrastructure for strong authentication and access to systems; and a web based authentication and authorisation infrastructure called Shibboleth. The AAF infrastructure can be federated across institutions and trusted by international collaborators.

  Further investment is required to develop and operate co-ordinated access and authorisation solutions for all research resources and capabilities. The access management solutions must also inter-operate with government authorisation systems.

- Data Storage: to provide data storage facilities (the hardware component) and data management plans (the principles for storage and long term preservation) to assist research.

  Building on the ARCS, a national data grid is needed to provide for long-term preservation of data. This national data grid would provide seamless unstructured storage as well as collaborative storage spaces, particularly focusing on but not limited to active research projects and research collaborations. A dedicated high performance network would link the nodes in the grid, allowing researchers to move data rapidly from instrumentation to computing resources and to institutional storage.

  This investment would extend to research organisations for the development of institutional nodes of the storage grid, on the condition that the storage is used for research data; the institutes co-invest in the infrastructure; each institute agrees a data management plan; and each institute ensures its researchers use and abide by the data management plan.

- High Performance Computing (HPC): to meet the needs of advanced "in-silico" science and the modelling and data analysis needs of complex system sciences. This component will build on the existing investment in the National Computing Infrastructure (NCI) that provides a peak computing facility accessible on a merit and priority basis and expert support for researchers who use it.

  Further significant computing needs exist as do new forms of computing aggregations so that the demand for HPC services is expected to grow for the foreseeable future.

  Continuing federal investments and research sector co-investment are required to provide the mix of facilities that can meet these growing computing needs. Three forms of support are required:

  - The development of specialised services, each contributing to a globally significant computing resource, that support priority research areas and bring together the necessary research and HPC skills with problem specific data and modelling capabilities;
  - A national HPC resource that can be made available to all researchers through an open merit allocation scheme; and
  - Special purpose facilities that provide tailored data analysis, real-time processing or visualisation services.

- High Capacity Communication Networks: to enable effective research and research collaboration by connecting research organisations, research activities and researchers. Future development will build on the investment in the Australian Research and Education Network (AREN), managed by AARNet Pty Ltd, that provides a high-speed core network between capital cities, interconnecting Australian universities, some research institutions, and regional and international research networks.

  Future strategic development of the AREN should focus on:

  - The continued extension of the reach and capacity of the underlying national backbone;
  - Provision of ad-hoc dedicated circuits configured on demand to support advanced experiments, computing grids and machine-to-machine interactions;
  - Extension of the AREN to government researchers and for research access to resources that governments hold and agree to share for research use;
  - Enhanced network capacity to international research organisations;
  - An enhancement strategy to improve network performance ahead of, rather than in response to, needs. This would be aided by a national co-ordination and investment management process that is independent of specific providers but takes account of research sector, state and territory government and overall provider interests; and
  - A strategic design activity to scope and align investments in backbone, regional and institutional network capabilities and to more fully develop the demand for advanced research network services in preparation for significant additional investment.

Transition Components provide the support and infrastructure to bring about an effective transition from research to eResearch with a focus on data federation, seamless collaboration and effective sharing of resources. They include:

- Shared Data: the national capacity to re-use and re-purpose data gathered for research and to make data that might be gathered for other purposes available for research. Based on the concept of an Australian Research Data Commons[4], ongoing investment and a very significant increase in resource is needed in:

  - Identification, registration and searching services;
  - Capability building at research institutions so as to appropriately gather, retain or preserve, curate and migrate data for re-use;
  - Policy development to agree and where possible simplify the arrangements around data, so that re-use and data integration are socially, legally and technically feasible; and
  - A case by case approach to assist research communities and data managers to integrate their activities and hence their data into the Research Data Commons.

  An additional challenge and task in building the Research Data Commons is to integrate datasets from all investments in research and research infrastructure. This will include harmonising other investments in data gathering, data generation from instruments and a variety of imaging and sensing deployments; as well as digitisation of existing collections.

- Shared Spaces: collaboration spaces that are managed in their own right and span the enterprise spaces provided by individual research organisations. These spaces will empower researchers to work with each other and more easily share and access global resources, including through web collaboration and video collaboration tools. They will enable researchers to access, annotate and analyse large-scale, distributed datasets that conform to world standard data formats and international discipline-based standard metadata schemas; as well as ingest, manage, annotate, analyse, share and publish their own data.

  In addition, shared spaces will enable researchers to use simple, customised user interfaces to perform large-scale simulation, modelling and analysis on high-end computing facilities; perform complex workflows that automate tasks currently done manually; and remotely manage and operate facilities, instruments and sensor networks.

  A mixture of case specific and general eResearch infrastructure tools and services will be needed to accelerate these integrative developments. Close interaction with each of the other research capabilities will be essential.

- Shared Infrastructure: the deployed tools, middleware and hardware that allow for the rapid integration and sharing of infrastructure. Examples include systems that allow the easy capture, pre-processing and visualisation of data from shared instrumentation (e.g. telescopes, synchrotrons, microscopes, laboratory information management systems), and remote access to sensor networks or the easy integration of outputs from ecological observational platforms.

4 For a better understanding of a Data Commons, see for example *Towards an Australian Data Commons*, 2007, available at http://www.pfc.org.au/pub/Main/Data/TowardstheAustralianDataCommons.pdf.

A key characteristic of eResearch infrastructure and its deployment and use will be a rapid co-evolution of the capabilities and their services. Significant barriers to evolution related to expertise, design, installation, and technological change management, especially as these are related to ICT and eResearch practice, will need to be overcome. The National eResearch Architecture Taskforce (NeAT)[5] will operate on a broader scale to support more intensive integrative projects. Such 'bridge building' will require the addition of investment on a discretionary basis for the development and deployment of shared infrastructure.

A **Coordination Component** is needed to further the development of eResearch infrastructure and assist the ICT enabled evolution of research practice.

- Governance: the scale of activity needs stronger corporate governance, especially if the application of longer term funding is to be managed.

  An appropriate governance role could include:

  - The ability to influence or direct funding to the development of next generation activities, to overcome the resource hurdle that currently inhibits the creation of 'new' services at the intersection of eResearch and other capabilities;
  - A mandate to assess and influence the business plans of the infrastructure components within this capability;
  - An ability to influence the ICT infrastructure within other capabilities so that a compatible eResearch infrastructure is created across all research fields; and
  - An ability to leverage institutional and eResearch activity in a coordinated manner.

  Stronger governance would also manage integration and change more effectively and allow stronger reliance on the eResearch services provided. This extended role would subsume the role of the Australian eResearch Infrastructure Council (AeRIC), which has been advising on the set up of the PfC investments.

- Leadership: to promote awareness of and achieve the research gains possible from advanced ICT, the coordinating component would also:

  - Build bridges between research infrastructure and research investments, assist government and academic research activities to inter-relate, and reduce policy impediments to collaboration;
  - Have the ability to speak for eResearch as a whole, to undertake strategic planning, to package eResearch support to meet significant national research needs and major national and international research collaborations; and
  - Provide the 'national voice' that could project Australian eResearch interests on the institutional, regional, national and international scenes; and, in particular, represent research interests in gaining maximum access to data and physical collections funded outside the research sector.

- Skills development: eResearch skills development will require attention in light of the consideration of expertise as an enabling infrastructure in this Roadmap. Valuing and keeping ICT staff and their expertise require career structures and rewards similar to the opportunities such skills enjoy elsewhere.

  The coordinating component, through its national voice and ability to support strategic investment decisions, can assist sector activities specifically targeting skills development.

To fully realise the benefits of eResearch, national investments must extend and complement ICT and eResearch support in institutions and by state and territory governments; and allow for the evolution and migration of services over time.

There is also a need to ensure that all research capabilities describe their eResearch support requirements adequately and that investment plans fund access to eResearch expertise, rather than competing for rare resources.

There is recognition that advances in eResearch will depend vitally on advances in research into ICT. As these advances occur in specific capabilities and require corresponding advances in research infrastructure, a coordinated approach to leverage these advances across the capabilities may also be required.

5 NeAT was established under NCRIS to develop and promote the adoption of new eResearch methods and tools.

Environmentally Sustainable Australia

Contextual Framework

One of the most significant challenges Australia faces today is the impact of increasing human population, resource use and climate change on environmental systems. A better understanding of environmental systems, and the effects of population growth and climate change on these systems, is essential to our ability to mitigate, respond and adapt to these changes and ensure the ongoing viability and sustainability of human habitation.

Broadly, environmental systems can be divided into the natural environments (terrestrial, marine, atmospheric and coastal zones) and built environments (man-made surroundings). Research related to the understanding of how these environments are structured, how they function, their vulnerability and resilience, and how they change involves a large range of disciplines across the physical, natural and social sciences.

Natural and built environments are complex systems, characterised by interactions of components or elements (e.g. nutrients, carbon, water, people) within specific spatial and temporal frameworks (i.e. geology, land-cover, biodiversity, cities). These environments are intrinsically connected to and supported by the earth, and knowledge of the Australian continent is central to understanding how the natural environment evolved, locating the minerals and energy resources it supplies, and anticipating and responding to the natural hazards it creates.

Detailed holistic studies are necessary for understanding the environmental systems and the earth, requiring multidisciplinary approaches and infrastructure to support the:

- Comprehensive, coordinated measurement and monitoring of environmental components and earth properties over the long term;
- Management of data acquired to ensure that all data collected is organised, retained, accessible and linked in a way that supports a variety of research activities; and
- Analysis and modelling that helps integrate and synthesise data, and enables the improved understanding of how these systems function and change.

Research Capabilities

The NCRIS program has enabled significant developments in priority research capabilities relevant to an Environmentally Sustainable Australia, specifically: the establishment of an Integrated Marine Observing System; formation of a national system, AuScope, for earth science covering geoscience and geospatial infrastructure; investment in advanced plant phenotyping facilities; support for the creation of the Atlas of Living Australia; and initiation of the development of a terrestrial ecosystems research network.

The continued and enhanced support across these capabilities is confirmed in this Roadmap, with emphasis on:

- Increased intensity and coverage of the integrated marine observing system;
- A specific focus on development of groundwater capabilities;
- Support of key research areas within the framework of terrestrial ecosystems; and
- Recognition of the built environment as a key area requiring research capability.

Terrestrial Ecosystems

Description

Australia has a large number of diverse natural ecosystems. A significant level of research activity is organised around the study of how these ecosystems are structured and function, how they respond to change, the role they play in providing resources and services, and how they can be managed in a sustainable way.

To promote excellent ecosystems research across these various areas, and to effectively understand the complex interactions between the components of terrestrial ecosystems – for example, the effects of altering vegetation coverage on water catchments and biodiversity – infrastructure is required that enables the collection of data, the coherent integration of that data, and the analysis and modelling of these datasets.

Strategic Impact

Strengthening our understanding of terrestrial ecosystem functions and their key drivers is vital to the health and sustainability of Australia's environment and to the enhanced management of environmental resources and services. This requires a national view of the status of ecosystems, enabled by the capacity to undertake collaborative and integrated research. In turn, achieving this integration requires infrastructure that facilitates linkages between researchers from the various ecosystem research groups and broader research communities.

Terrestrial ecosystems encompass soils, landscape, climate, biodiversity (including phenomics) and water, and are linked through productivity and nutrient transfer into estuarine and marine environments. 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 landscapes and vegetation are under threat from problems such as salinity, land degradation, scarcity of freshwater resources and loss of biodiversity, and the effects of human-induced climate change.

There is a critical need for understanding the processes and interactions within *and* between these aspects of terrestrial ecosystems. Without a comprehensive, holistic and coordinated capability to adequately measure environmental parameters (such as carbon and water) over long periods at a variety of scales, to improve the information base that underpins Australia's environmental research and management efforts, our ability to understand and deal with environmental change will be inadequate.

Challenges and Assumptions

The 2006 Roadmap recognised the magnitude of the task to improve the quality and level of collection and integration of data relating to Australia's terrestrial ecosystem. The extent of the task derives firstly from the complexities of the systems being studied and secondly from the number of organisations and jurisdictions involved in environmental research and management.

The Terrestrial Ecosystems Research Network (TERN), funded under the NCRIS program, is being developed as a catalyst to change the planning and coordination of ecological research at a national level, whereby a national framework is established to provide an overarching and integrative role. TERN will initially focus on implementing a national governance arrangement, data management, access, modelling and analysis capabilities, in order to promote collaborative behaviours through a national strategic approach and lead to research outcomes that have an impact on policy and management decisions. Specific efforts are being directed at harmonisation of disparate datasets, access to and calibration of remote sensing data, nationally consistent observations at flux sites, and the principles for design of future TERN observing infrastructure.

An ongoing and significant challenge is the implementation and maintenance of a long-lived site and observing network that supports research and management at a range of scales from regional to continental. Detailed site observations can be used to calibrate and inform regional and continent-wide investigations, and observations made at regional scales allow the context for site investigations to be established. This requires systematic planning of how both local and regional observational data and information can be cascaded upwards or downwards as inputs into research, and agreement as to the sites that form the core of the system and the common monitoring and reporting protocols. Collaboration and coordination between universities, public research organisations and relevant state, territory and federal government agencies is critical to the success of such a network.

The coastal zone is home to most of the Australian population and is under increasing environmental pressure. An important need exists to develop approaches to link capabilities established under TERN and the Integrated Marine Observing System (IMOS) that can support appropriate research on coastal issues.

The further development and use of enabling capabilities in remote sensing, data management and access is essential to an improved terrestrial ecosystems research capacity. It is important that this is undertaken in a coordinated manner through linkages with programs and expertise in the geoscience and marine communities.

Requirements

Infrastructure

The initial investment in TERN is seen as establishing the first stage of a national integrating framework with focus on data management infrastructure; capabilities for the analysis and modelling of data; and the engagement of the ecosystem community in commencing the establishment of national reference sites and observing systems to support the terrestrial aspects of climate modelling. These processes will provide the mechanisms to design further infrastructure requirements for site and observation networks that can deliver the necessary data streams that facilitate integrative research and support resource management requirements.

If the long-term commitment of institutions and researchers to this framework can be consolidated, further investment is likely to be needed in:

- Expanded data management services to support discovery, access and interoperability of datasets, and national coordination in areas such as developing metadata standards;
- Tools for linking and analysing datasets, for input to models and determining where data gaps exist;
- Provision of enhanced fit-for-purpose models and predictive capabilities; and
- Further development of a priority network of baseline sites, ‘super sites’ and long term ecological research sites, with agreed measurement protocols, sensor technologies and networks for improved and coherent measurement of parameters in priority ecosystems.

Within the various research areas covered by terrestrial ecosystems, specific infrastructure needs include:

Biodiversity

Further development of predictive modelling capabilities and spatial data presentation and visualisation techniques is needed. These would build on the NCRIS investment in the Atlas of Living Australia, which is providing a platform for understanding the aspects of terrestrial, freshwater and marine biodiversity by databasing and linking biological collections and environmental datasets that are important for improved use of significant resources.

In continuing to develop the Atlas of Living Australia, support for the prioritised digitisation of the most relevant and important elements of Australia’s natural history collections is required to provide access for researchers to critically useful biodiversity information. This will be vital to understanding environmental change and will have other applications in areas such as biosecurity, biodiscovery and biomedicine.

The development of environmental genomics facilities for the collection and analysis of biodiversity data is an area of emerging importance that can enable the integration of genetic information with spatial information layers to understand species distribution and habitat features. The establishment of links with genomics platforms under the Integrated Biological Discovery capability should be supported.

Soils and Landscapes

Investment in tools that help further develop methods for monitoring soil condition is needed to enable better monitoring of soil carbon sequestration to support initiatives such as the National Carbon Accounting System and to allow long-term studies of spatial distribution of soils and their changes over time (e.g. water storage, carbon dynamics and nutrient availability). This should include consideration of emerging techniques for soil genomics, as part of a broader environmental genomics capacity. Infrastructure for vegetation sampling and analysis is also required.

Figure C

Continued support for the development and service provision of advanced plant phenotyping techniques is required. This would build on the capacity being established through the NCRIS-funded Australian Plant Phenomics Facility (APPF), which is improving our capability in biological systems by consolidating expertise and technologies for molecular biology, advanced genomics and plant phenomics. The platform technologies being developed by the APPF collaboration have application not only to ecosystems research and natural resource management, but more broadly to many areas of plant science that underpin research relevant to agriculture (including food security), bioenergy, horticulture and forestry.

Freshwater

Improved capacity for measurement and monitoring of freshwater resources and biodiversity is required. Investment should be coordinated with key initiatives including the CSIRO Water Resources Observation Network, the eWater CRC development of river and groundwater capacity and the Bureau of Meteorology's Australian Water Resources Information System, and state government programs.

Support

The availability of generic ICT services around data, networks, computational modelling and visualisation, and agreements for data use and sharing will be critical to TERN.

Support from eResearch providers in the collaborative development of data management and access capabilities is required. Skilled technical people to support data acquisition, modelling and simulation infrastructure are essential.

Coordination and establishment of governance frameworks that enhance partnerships between researchers and institutions, and link to agencies in jurisdictions, are essential if an appropriate strategic planning approach to research and research infrastructure in terrestrial ecosystems is to be achieved.

Built Environments

Description

Built environments consist of man-made surroundings for human activities, such as cities and urban areas (from large scale civic surroundings to personal use), and the supporting infrastructures of transport systems, water supply, wastewater, stormwater, energy supply and recreational assets.

The capacity to understand the physical and social aspects of built environments is essential in improving the sustainability of cities and urban areas. Research to support this understanding requires facilities that enable the collection and integration of datasets in energy and water consumption, resource management, and social and environmental interactions[6].

Strategic Impact

Understanding and modifying the forms of large, urban, built environments where the majority of people live is fundamental if Australia's environmental sustainability is to be improved. Built environments need to be understood both as physical sites whose systems may be the subject of scientific analysis, and as a social site in which human behaviours occur that themselves have consequences for environmental sustainability.

The collection and integration of datasets on human behaviour, including consumption of natural and urban resources, are required to develop ways for large, urban, built environments to be modified so that they are able to adapt to changes in natural environments due to for example climate change, and also to modify human behaviour that directly impacts on sustainability.

Challenges and Assumptions

A key challenge for research in built environments is the need to establish and enhance linkages between the physical and social sciences, and to facilitate collaboration and 'systems' approaches to studies into environmental sustainability of Australia's cities and urban areas. This requires infrastructure including research networks and connectivity of datasets (such as demographic) across discipline areas.

Critical factors in accelerating solutions to global ecological challenges include: exploitation of digital data-gathering and processing powers of ICT to more accurately inform decision-making in urban development; the need to gradually integrate specialist expertise from built environment professionals, environmental science, engineering and the creative professions; and the need to apply ecological strategies at the scale of the city.

6 The concept of 'integrated practice' has been used to acknowledge the emergence of a teamwork strategy that reflects the need for multi-disciplinary research collaborations on sustainable built environments.

The establishment of mechanisms for coordinating data collection across research institutions, jurisdictional agencies including council and state planning groups, and possibly the private sector and the general public, will be necessary if a national infrastructure for collecting and integrating datasets on built environments is to be achieved.

Requirements

Infrastructure

Further scoping should be undertaken to identify and prioritise specific infrastructure needs in the following areas:

- To document the consumption of energy and water, development of large-scale, nationally-consistent datasets of energy and water use in Australian urban systems must be undertaken by a coordinated network of planning and environment organisations.
- To improve the management of urban resources, the infrastructure needed includes: physical facilities and skilled people for testing building materials for re-use; and equipment for real-time measurement of urban resources for the development of smart systems (for example for stormwater management).
- Investment is needed in facilities for modelling social and environmental interactions, including the development of 'virtual cities' as test beds of sustainability. This would include collaborative design and research spaces to enable shared access and use of datasets and visualisation models.

Support

Links to enabling eResearch services and expertise will be critical, in particular through the Australian National Data Service and the Australian Research Collaboration Service. There will also be significant potential to draw from the Transforming Humanities, Arts and Social Science Research capability, particularly in relation to the use of data around social and cultural aspects of built environments.

Marine Environment

Description

Understanding and ensuring the long-term health and productivity of Australia's marine estate and related industries, and predicting climate variability and change, requires a continued and strengthened capacity to accurately and rapidly detect and predict changes in the ocean environment, coastal ecosystems and marine living resources.

An integrated and coordinated approach to collecting data (both remotely and via research vessels), storing, managing and making accessible this data, and modelling to support the interpretation of the data and inform predictions, is essential to supporting the research activities that build the understanding and management of our marine environment.

Strategic Impact

The recent expansion of Australia's marine jurisdiction[7] has placed further emphasis on the need to better understand and manage our marine environment. Whilst Australia has an excellent research capacity in ocean ecosystems and marine environments, the large and complex nature of our marine environment requires a sustained and enhanced research effort and supporting infrastructure.

There is a significant need to enhance Australia's research capabilities to better predict climate change and respond or adapt to its impacts on the environment. Given the key role that ocean processes play in climate systems, Australia needs to ensure its marine observation system is comprehensive by expanding its coverage and augmenting the intensity of its marine observation efforts. Such an enhanced capability is equally important to the improved management of the marine environment, including the use of biological and seabed resources, the protection of ecosystems that are under threat from man-made influences, and more broadly to applications across national security and marine safety.

Challenges and Assumptions

The Integrated Marine Observing System (IMOS) established under the NCRIS program brings together over 30 participating organisations in the coordinated deployment of a wide range of equipment aimed at deriving critical datasets that serve multiple applications. Data streams provided through IMOS support research on the role of oceans in the climate system and the impact of major boundary currents on continental shelf environments, ecosystems and biodiversity.

A long-term commitment to a sustained and enhanced IMOS is necessary to delivering the capability required to understand and manage Australia's marine environment. The need for more concentrated and frequent marine observations to take place and to occur in areas beyond the current coverage of IMOS, such as the North/North West coast of Australia, will significantly improve our ability to measure key critical parameters (such as temperature) which are important to understanding change in climate and ecosystems.

Figure D

The delivery of a coherent and coordinated marine observation system is underpinned by an ongoing, robust national framework for planning and coordination between marine science agencies and the wider marine science community. The Australian Government Oceans Policy Science Advisory Group is an important element of this framework, and can support the promotion of collaborative approaches in areas such as data sharing and standards.

Active engagement with international science initiatives including the Global Oceans Observing System and the Partnership for Observation of the Global Oceans is a key requirement for strengthening Australia's marine research capacity and maximising the research outcomes. Strategies for securing ongoing and long-term support for participation in these initiatives are required.

A platform for blue water research is essential if Australia is to have the capacity to undertake world-class science and participate in international programs. A number of issues surround a decision on Australia's future blue water platform: short term support of the current vessel, the Southern Surveyor; replacement options including building a new vessel or pursuing long-term charter; single versus multiple platforms; the capabilities of the platform to deploy marine research infrastructure such as sensors and remotely operated vehicles. These issues require consideration within the context of a landmark facility infrastructure proposal.

7 This follows a review by the United Nations Commission on the Limits of the Continental Shelf.

A broad challenge for the marine and terrestrial, geoscience and atmospheric research communities is to coordinate activities related to sensor applications, data sharing, and development of analysis tools and models, with the goal of supporting more effective and holistic research programs on issues of significance such as climate change. The shared use of platforms and equipment to understand marine habitats and ocean floor geology would also benefit from enhanced cross-capability linkages.

Requirements

Infrastructure

Key future infrastructure needs will include:

- Additional monitoring systems, instrumentation and sensors across the suite of facilities that have been established under IMOS, to support wider geographical coverage and increase the intensity of measurements;
- Access to molecular biology technologies and tools to support marine observations, where possible building links to –omics platforms delivered under the Integrated Biological Discovery capability;
- Enhanced data management and analysis tools, including modelling capacity;
- Network support to enable connectivity between datasets in different jurisdictions or housed on diverse networks; and
- Common data standards to govern the management of data collected, including discovery, sharing, integration and curation of data.

Support

Support includes through: ICT networks; common data approaches across marine, terrestrial and continent (including data schemas); and governance and coordination mechanisms to build and enhance linkages with terrestrial ecosystems and geoscience infrastructure providers.

Australian Continent

Description

The geological structure of the Australian continent: provides the foundation upon which our modern environment is supported and is dependent; provides our mineral and energy resources; and is the source of natural hazards.

The capacity to obtain accurate information on the Australian continent is an important capability supporting both our understanding of the fundamental geological processes and structures, and the manner in which they evolved over time. Important infrastructure elements contributing to this capability include: facilities to acquire and study geophysical and geochemical properties of earth structures and materials; an accurate geospatial reference system; systems for the management, access and interoperability of large and complex datasets; and simulation and modelling software tools for advanced analysis.

Strategic Impact

The geosciences play a major role in dealing with some of the biggest challenges and opportunities facing the Australian and global communities, including:

- Climate change, through understanding past climate patterns and identifying and assessing opportunities for reducing adverse impacts;
- Supporting the discovery and cost-effective, sustainable use of minerals, energy resources (including potential new energy sources such as geothermal), and groundwater resources; and
- Providing understanding and early warning of natural hazards such as earthquakes and tsunamis.

Australia has world-class expertise in geological sciences research, which serves to better understand the structure and evolution of our continent and plays a vital role in the economic wellbeing of Australian society. Progress in this area requires the continued and collaborative development of infrastructure that meets the needs of strategic and emerging areas of research. Such infrastructure must be accessible and must enable integration of research efforts across the various disciplines.

In a period of climatic uncertainty and diminishing surface water storages, groundwater is a critical but poorly understood resource. Research into determining the extent and nature of Australia's groundwater resources is necessary to improving our understanding and potentially increased use of this important resource, and will depend on strengths in the geosciences.

Challenges and Assumptions

The establishment of AuScope under the NCRIS program is facilitating the implementation of an integrated infrastructure system for earth science, through the delivery of a range of technologies and capabilities in data acquisition, management, modelling and simulation across the geospatial and geoscience spectrum. This infrastructure system is enabling the construction of a 4-D 'earth model' of the Australian continent that can serve a range of users in research, policy, industry and education.

Through the involvement of universities, national research agencies, state and territory governments and industry, AuScope is providing a nationally collaborative and strategic approach to the planning and development of infrastructure to underpin Australia's geoscience research. Continued support to enhance and evolve AuScope is vital to maintaining Australia's world-class abilities in this area, engaging with industry and international groups, and sustaining the collaborative behaviours of this community.

Considerable effort is being devoted by the geoscience community to the development of capabilities for management and sharing of large datasets and the tools to analyse this data and develop models. Whilst this is an ongoing challenge, significant potential exists for the wider application and coordinated development of these capabilities across other research areas including terrestrial ecosystems.

In relation to groundwater, a National Centre for Groundwater Research and Training has been recently established under the auspices of the Australian Research Council and the National Water Commission. Planning and development of supporting infrastructure for groundwater research should be informed by discussions with this Centre.

Requirements

Infrastructure

Sustained and enhanced data acquisition, data management and modelling and simulation capabilities building on those being implemented through AuScope will be needed. To meet increasing user demand, additional capacity is likely to be required in:

- Earth imaging to provide greater coverage and geophysical data (seismic, electromagnetic) across large areas of Australia;
- Geochemical instruments such as ion probes to support advanced analysis of minerals;
- Geospatial systems, to improve accuracy and time resolution for geoscience and other research areas that require spatial data; and
- Further investment in dedicated ICT in particular data storage and modelling capabilities.

In relation to groundwater, specialised systems for monitoring water cycle components, boreholes, and acquiring geophysical data are required. Linkages with infrastructure developments in sensor networks, data integration and modelling capacity under the Terrestrial Ecosystems capability should be promoted.

Support

Support from eResearch providers in the collaborative development of data management and access capabilities is required. Skilled technical people to support data acquisition, modelling and simulation infrastructure are essential.

Humanities, Arts and Social Science

Contextual Framework

Responding to today's global, social, cultural and economic challenges requires specialist knowledge of the people, societies and cultures that underpin, fuel or react to these challenges. Humanities, arts and social sciences (HASS) research is integral to achieving this fine-tuned understanding. The inclusion of this capability in this Roadmap to address the research infrastructure needs of the HASS disciplines reflects the clear articulation of these needs by the community and recognises the importance of HASS as a priority research area.

Description

For the HASS sector in Australia to sustain its impact on society and build on its internationally recognised reputation in research across a wide range of established disciplines and new interdisciplinary fields, a transformative step is needed on how it approaches research. This step will be characterised by the adoption of systems comparable to those in North America, Europe and the UK. Investment in a purpose-built, accessible, interoperable and dedicated HASS eResearch infrastructure will transform current research practices across the three discipline clusters; as well as generate efficiencies, facilitate innovation and drive international collaboration.

- In **the humanities**, new technical capacities for the electronic analysis of texts and for the construction of virtual environments incorporating sound, moving vision, text and artefacts of various kinds can continue to revolutionise research practices in many disciplines.
- With the help of grid technologies, imaging and visualisation laboratories, and the integration of social, historical and cultural data using advanced design technologies, research developments in **the arts and creative industries** in Australia have the potential to rationalise existing project-based investment, enable international science-arts collaborations and enhance links with industry.
- Australia will match international best practice **in social science** data access and analysis by establishing the necessary infrastructure to connect the capacities currently housed in freestanding, project-based, data bases, as well as create and maintain the collection of longitudinal and time series data for tracking major social, economic and behavioural trends.

This capability will therefore provide appropriately tailored eResearch infrastructure that supports and aligns with the nature of HASS data and research materials, with ancillary training capacities and the disciplinary approaches to guide how data is shared and used. The capability will develop two broad and connected elements of eResearch infrastructure: data creation - through digitisation, systematic capture of 'born digital' materials, and support for national survey instruments; and data management – including curation and dissemination through national platforms. Significantly, these new forms of research would complement and integrate with more traditional forms of research.

Strategic Impact

This capability will address the sector's capacity for the creation, retention, management and collaborative use of data within and beyond the HASS disciplines. It will capitalise on, benefit from, and advance the efficiencies and innovations delivered by the dramatic international developments in the practice of HASS research.

The capability will transform the impact and international standing of HASS research from fields as critical and diverse as history, sociology, economics, international relations, visual arts, literary studies, design, demography, anthropology, archaeology, cultural geography, and cultural studies.

In key areas of social and economic policy such as international relations or indigenous policy, more accurate predictive modelling of social, cultural and economic behaviours and the linkage of HASS data across large scale databases can be used to examine the long term impacts of government policy and interventions.

In some spheres, a HASS discipline is the principal area of inquiry that dominates the development of a policy or strategic standpoint. In others, such as the response to natural disasters, the contribution of one or more HASS disciplines can be critical to determining the nature of the approach taken by government and other bodies.

> 'As Australia globalises and internationalises, it faces complex issues around social cohesion, multiculturalism, its sense of place, of its varying histories, its multiple narratives, which shape a unique society. Social enquiry, cultural analysis and production underpin the development of essential new understandings of a rapidly-changing position in the region and on the world stage.'[8]

In an increasingly connected world, research infrastructure that both enables the research and makes it widely accessible is vital.

8 Curtin University, Response to Discussion Paper released under the review of the 2006 Roadmap.

While a purpose-built dedicated HASS capability is urgently required, it will be directly related to the funded capabilities in recognition that HASS research is intrinsically relevant to the policy domains in which initiatives under this Roadmap are located. HASS researchers will therefore gain from as well as contribute to research activities supported by other capabilities, such as the population and biological health data network, terrestrial ecosystems, marine environment, and networked biosecurity. The capability will strategically position researchers through better access and sharing of research data between HASS disciplines and all others. It will provide the base for sound, resilient and longitudinal data that is critical to the productive interaction on research problem areas that cross the capabilities.

- The proposed infrastructure will facilitate a shift from individual to collaborative, project-based research; enable the expansion of the benefits of research data and resources currently restricted to small groups of users or projects; and allow new connections to international collaborative research platforms and resources.
- A HASS eResearch infrastructure will enable HASS researchers to undertake established research activities in better and more efficient ways, enhancing the possibilities for interdisciplinary, cross-institutional and national collaboration, while rationalising the use of existing resources.
- Equally importantly, the capability will enable researchers to undertake different forms of research by using new capacities to create, collect, analyse, manipulate, visualise, compare and re-use data.
- Skills built in these areas in HASS will be transferable and relevant across capabilities; the future uses by HASS of visualisation, for instance, will be applicable to many disciplines.

Challenges and Assumptions

Strong collaboration between and within the three broad HASS fields addressed by this capability will be vital to its success. Feedback during the review supports the focus and objectives of the proposed capability and demonstrates a firm commitment to their implementation. A platform of existing achievements within the sector, in university-based and other institutional digitisation, data management and linkage, can form a basis to this capability. This capability will serve to both electronically network these achievements and enable significant development of their scale and focus. Such projects include:

- Digitisation projects in the National Library and in the various state libraries and museums;
- The Collections Council of Australia's development of a National Strategy for Digital Collections;
- Collaborative enterprises in social science data, including NCRIS-associated ones such as the Australian Bureau of Statistics (ABS) National Data Network (NDN) and the Australian Social Sciences Data Archive (ASSDA);
- Projects such as the Ageing Research Data Archive, Austlit, PARADISEC, i-Cinema, the Spatial Information Architecture Laboratory; and
- Two Academy of the Humanities research projects under way, that focus on digitisation and the humanities' use of new technologies.

It is acknowledged that HASS research includes data that may be sensitive from a cultural, individual or other perspective, and this needs to be appropriately catered for.

The broad and very diverse coverage of HASS will be a particular challenge requiring the early establishment of an appropriate and committed governance mechanism to foster cohesion in the capability and to establish a guiding framework that recognises the variety of disciplines and the complexity of their infrastructure and resource needs.

Requirements

Infrastructure

Dedicated access to eResearch infrastructure is needed that is open enough to allow discovery, sharing and leverage of data by HASS researchers and those of other disciplines; and enables innovative and internationally comparable ways of creating, analysing and modelling data within HASS. Two broad streams of work are proposed, in addition to which key support mechanisms are required to support both streams:

1. **Data creation and digitisation of research materials** – this stream is concerned both with the reformatting, preservation and curation of existing data (textual, visual, and multimedia), and the adoption of new techniques to improve the capacity for data to be born digital. A key goal is to enhance the access and distribution of this data beyond traditional reach and timeframes. The stream will complement and build on current institutional retention of the data in research and collecting institutions:
    - It will enable the conversion of key primary research analogue data to digital form: the materials envisaged here include such historic materials as photographs, maps, and journals; heritage material such as literary texts and material collections such as the Australian folklore collection; and long term social survey data not currently in accessible form (such as pre-digital ABS data).
    - It will also facilitate the creation of additional data for ongoing databases, such as is necessary for the continuing integration of longitudinal and survey data into existing databases.
    - Given the magnitude of the task of digitising HASS data, this component will be characterised by a strategic approach that consults with the reference groups in order to set those priorities that deliver the best value for the investment.

2. **Data management and linkage** – this stream will set out to bring cohesion to the way data is linked, retained or archived, and curated to develop distributed data repositories that can be accessed and used most effectively. In the first instance, the reference group would assist in finding ways to interconnect existing Australian databases in a network that would then seek reciprocal linkages with comparable international databases. To enable researchers to gain improved access to current and past data series collections in HASS areas, and to facilitate collaboration with comparable international studies, key services will be made available, including:

    - Enabling the data and their repositories to be interoperable, accessible and appropriately secure;
    - Providing the appropriate networks to connect HASS with other researchers;
    - Data modelling and analysis tools;
    - Visualisation capabilities (including for multimedia, video, sound, animation, creative arts); and
    - Collaborative tools and platforms.

These two dimensions of the capability would be connected electronically so that the whole environment was searchable, interoperable and as broadly accessible as possible. This would ensure the capability operated as a strong collaborative platform – as a shared research infrastructure not only for those HASS researchers contributing directly but also to those who wished to seek, connect or collaborate with HASS researchers.

Related to this challenge is the need for the development of appropriate software and analysis tools to enable both existing and new modes of research. Virtually every HASS discipline would have requirements for specific but transferable tools that take advantage of evolving ICT capacities to transform research practice.

Support

<u>Skills</u>: Access to the appropriate ICT infrastructure will facilitate the ability to upgrade the expertise and skills needed to assist researchers to work within these new contexts. A key challenge for this capability is the recruiting and training of suitable personnel with a close alignment to or a background in a HASS discipline as well as appropriate ICT skills. From the outset the capability must address the training of personnel to work directly with HASS researchers in their interface with the technologies and to raise the skill levels of HASS researchers themselves in this regard.

It is acknowledged that this is a common issue across the capabilities that may be dealt with at a broader level. However, the transformative nature of the HASS capability suggests that focused attention in relation to eResearch skills and expertise be given to HASS communities as a matter of priority and as a fundamental objective of the capability.

<u>Governance</u>: As noted earlier, a peak governance body is needed to coordinate and promote these new capabilities for HASS research and to provide an essential basis for the complex collaboration needed to optimise this capability. The peak body is proposed to be a small but high level coordinating committee that would guide the strategic objectives of the capability in close consultation with stakeholders in the research sector and in the collecting institutions, directing and coordinating the various streams within the capability, as well as setting the terms through which the various platforms of collaboration would operate. The committee would oversee the careful and deep scoping of the ICT requirements for HASS through the engagement of the eResearch Infrastructure capability, with which it would cooperate to ensure coordinated development of the ICT infrastructure and services.

Supporting this committee would be two broadly representative reference sub-groups to align with the two streams of work proposed. These reference groups would provide advice from across the research community and collecting institutions on the specific programs of development in which the capability would invest. The participation of the reference groups would assist in maintaining the strong and focused communications, consultation, and outreach activities needed to reach consensus on specific elements of the capability and its funding recipients.

One reference group would primarily provide advice on the digitisation strategies for new and interlinked collection materials, for cultural heritage materials, and for issues on curation, preservation and management of such materials. The second reference group would be focused on more quantitative data-based management, the linkage of existing data, and the maintenance of data collection in longitudinal, comparative and other collections.

Case studies

Researchers working in the national priority areas of health, environment, frontier technologies and security have expressed their need to find ways to enable researchers in the humanities, arts and social sciences to participate in their projects if they are to address effectively the significant issues facing Australia. The case studies below illustrate two existing research strengths and associated infrastructure needs that are representative of how the HASS sector could be powerfully transformed through a sustained investment to build its capability.

HASS linkages to other areas of research: *PARADISEC*

– the power of language and culture in promoting and maintaining good health, safeguarding Australia, and the environment

The Pacific and Regional Archive for Digital Sources in Endangered Cultures (PARADISEC) is an exemplary HASS capability project, undertaking digital conservation and provision of international access to research resources in audio, text and visual media on endangered cultural heritage in Indigenous Australia, the Pacific Island nations, and East and Southeast Asia.

The project is known internationally for its development of low cost techniques for recording, accessioning, cataloguing and digitising complex cultural resources in digital media.

PARADISEC has immense and yet unrealised potential to contribute to national research priorities in health, the environment and safeguarding Australia. In respect of health, it is clear that in both Indigenous Australian and Asia-Pacific communities, the success of health initiatives depend on research that is deeply informed by understanding of the key linguistic and cultural determinants of health and well-being within what are often small societies with unique histories and endangered cultural heritage. In respect of safeguarding Australia, government has concentrated on security and governance issues over the past decade, but has not placed equal emphasis on creating robust cultural relationships.

PARADISEC has the potential to provide Australian researchers with the capability to pursue new research strengthening knowledge of the cultures of our closest neighbours in the Asia-Pacific, while empowering, deepening and intensifying government policies relating to these nations. The project also has immense potential to facilitate research cooperation between Australian and Asia-Pacific cultural institutions, promoting economically valuable outcomes such as growth in cultural tourism.

Finally, PARADISEC is a growing reservoir of knowledge relating to indigenous understandings of ecology and uses of natural resources in our region that are of immense value to researchers seeking to explore the cultural and social implications of climatic change and improved environmental management.

HASS: Indigenous Knowledge and Culture – making a difference

Australian research is highly regarded among the group of countries where indigenous ‘First Nations’ are present. This research covers virtually all disciplines in the humanities, arts and social sciences and has resulted in a plethora of digital resources and collections that are accessible under highly variable conditions. Key historical documents and other textual sources require digitisation to enable on-line access; and many important data sources remain locked away from researchers as culturally sensitive protocols and access arrangements have to be negotiated, often on a case-by-case basis.

Harnessing this knowledge and maximising researcher access will require the creation of infrastructure and eResearch tools under the HASS capability to resolve: digitisation priorities; linkage of collections and distributed data resources; efficient search and download mechanisms; and specialised tools and software to be developed to enable analysis and automated access regimes that respect the ethical and cultural sensitivities surrounding indigenous data and knowledge.

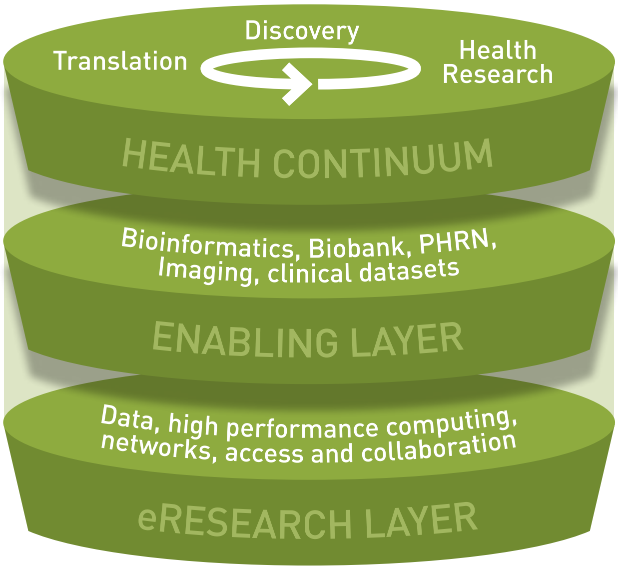
Alongside the research motivation for developing a highly sophisticated platform is an equally compelling case for the HASS sector to deliver the research and evidence that will enable a broad range of public policies to be developed to ameliorate and advance the economic, social and cultural conditions of our Aboriginal and Torres Strait Islander communities. In the same sense that governments have recognised that holistic, whole-of-government approaches are required to make progress on a broad front, a national collaborative research platform that meets these policy objectives is essential to efficiently draw together the quantitative and qualitative evidence that makes this possible.

Biological Discovery and Health

Contextual Framework

Health research spans from molecular biology through cellular networks and biological systems to individuals, populations and communities. Evidence derived from each part of this research continuum can inform a discovery and translation process designed to generate better solutions to existing health problems and to prevent where possible the emergence of new problems.

Figure E



Advances in health research are supported by a specific enabling infrastructure and capacity which is in turn underpinned by a relevant suite of ICT solutions. A key component of such infrastructure is the capacity to bring together large datasets which may describe, for instance, the behaviour of molecules, cells, biological structures or people in order to provide the best evidence base to inform research questions and strategies in biomedical, clinical or population health. The capacity to generate, analyse, link and interrogate such large datasets is an enabler of powerful health research.

Australia is currently in a unique position to:

» Build on its current research efforts to derive value from genotype to phenotype correlations across linked biological datasets from animal and human studies;

» Build new clinical datasets harnessing structural and functional markers of disease;

» Generate and link biomarker data from existing large population studies with measures of individual health; and

» Collect and link geospatial and demographic data to population datasets to address novel questions of relevance to the social determinants of health.

In biomedical research, there is also an increased international emphasis on how new and useful information can be derived by working across the leading edge of fields including biology, nanotechnology, robotics, information technology, engineering and mathematics. This fundamental scientific activity promises to generate and inform new solutions, and paradigm shifts, for the diagnosis, screening, therapy, monitoring and management of patient health and for the practice and delivery of medicine/health services and disease prevention.

Included in the key challenges to promoting and maintaining good health in Australia is the increase in chronic ill health and the emergence of complex interactions between the social and physical determinants of health that are associated with the ageing of individuals and populations.

The following proposed investments in infrastructure capacity have been developed in the context that it is important to recognise the value of the path from biological discovery, through translation into the clinic and community-based interventions, to ensure improved individual health, an evidence base for preventive health strategies and a more effective health system and service.

Research Capabilities

The NCRIS program has made investments in priority areas relevant to Biological Discovery and Health, specifically: the establishment of a nationally distributed facility, implemented through Bioplatforms Australia Ltd, that integrates some key nodes of existing capability and service provision in genomics, proteomics, metabolomics and bioinformatics; the formation of the Australian Phenomics Network to optimise access to superior mouse models of disease and associated services; the National Imaging Facility, a core Characterisation capability applicable to health; enhanced capabilities in recombinant proteins and the manufacture of human cells for transplant; and initiation of the development of a Population Health Research Network.

The continued and enhanced support across these capabilities is confirmed in this Roadmap, with emphasis on:

» Enhanced linkages between the related capability areas and a broadened bioinformatics capacity;

» Keeping pace with technical developments such as in genomics and high throughput screening;

» Support for a capability to translate health discovery into clinical applications; and

» Expansion of the national resource of health data.

Integrated Biological Discovery

Description

The development of platform technologies and rapid throughput methodologies to screen the structural and functional components of living cells and biological systems has generated an unprecedented level of functional information and large datasets. There are clear challenges to screen, manipulate and translate this information across a range of fields and to generate new knowledge which informs and improves our understanding of the fundamental basis of health.

Integrated biological discovery is a capability which delivers an integrated 'systems biology' capacity to the research community through:

- A consolidated capability comprising three distinct, though integrated bioplatform technologies – new generation genomics, proteomics, and metabolomics;
- High throughput screening (HTS) of small molecules (chemical and biological) and related medicinal chemistry capability for drug design and development;
- Enhanced bioinformatics, to harness the full potential of genomic, proteomic and metabolomics datasets and allow the integration of datasets across the platforms; and
- Animal models in which understanding of cellular biology can be extended to investigations of complex systems biology, health through the life course and the course of a disease, and effects of treatment.

Strategic Impact

Developing the platforms for integrated biological discovery will enhance and add value to Australia's fundamental research output, through ensuring access to integrated leading edge infrastructure and promoting multidisciplinary approaches to research.

In a fast moving global research environment, this capability needs to be enhanced if Australia is to maintain an internationally competitive position. For example, new rapid high throughput DNA sequencing technologies allow the feasible and cheap sequencing of whole genomes and rapid screening for subtle genetic variances. There is currently a significant growth in demand for proteomics especially in biomarker discovery and biomarker validation (including protein/antibody microarrays and protein interaction emerging technologies) both in Australia and internationally, from the traditional medical research community and from the agricultural and animal health sectors. Australia also needs to establish an improved capability in metabolomics, a discipline which provides an instantaneous snapshot of the physiological status of a cell, tissue or whole organism. Metabolomics provides a valuable and powerful connection between genomic and proteomic analysis.

However, there are new elements in the international discovery effort that need strengthening to ensure that Australia is well placed to better understand complex biological systems and bring innovative discoveries and products to market. The understanding of biological systems through perturbation by siRNA[9] or small molecule libraries has been given a high priority in several countries but, apart from small investments, Australia has not yet embraced the HTS paradigm and stands to lose ground, both in terms of the quality of basic research that can be produced and in downstream applications.

Maintaining an internationally competitive position reaps enormous benefit by enabling a stronger engagement with industry and research communities both within Australia and internationally. For example, the investment under the NCRIS program in a high throughput monoclonal antibody facility provides a massive competitive advantage to Australian researchers[10], and will attract biotechnology companies and pharmaceutical companies from around the world. Australia's standing in the international proteomics community has been recognised by its selection to convene and host the International Human Proteome Organisation meeting in Sydney in 2010. The European Molecular Biology Laboratories (EMBL) are negotiating to establish a series of partner laboratories in Australia, the first non-European country to host EMBL research laboratories. This association with EMBL provides access to external research funding and unique infrastructure including highly specialised bioinformatic capabilities and databases through the association with the EMBL-funded European Bioinformatics Institute.

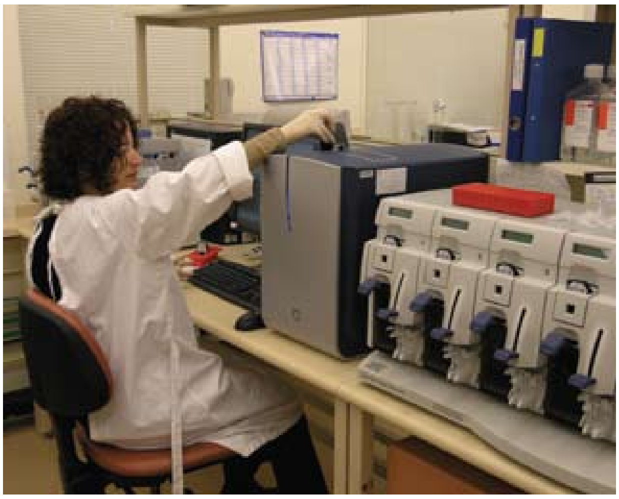
Challenges and Assumptions

A strong start has been made under the NCRIS program with the establishment of BioPlatforms Australia Ltd (BPA) and the Australian Phenomics Network (APN). Integration is evolving through these initiatives and now needs to be sustained through a longer-term commitment to support and build on the foundation facilities. Integration across and strategic co-ordination of platform activities both within BPA and other capabilities such as Characterisation and Terrestrial Ecosystems is critical, and bioinformatics has a crucial role to play. In this context, it will also be important to maintain and enhance existing links established under the NCRIS program between the APN, the Australian Plant Phenomics Facility and the Atlas of Living Australia.

Investment in staffing has been important to the success of these NCRIS funded capabilities. However, it is clear that there is a severe shortage of personnel skilled in the operation of these high level technologies. There is now a major requirement to invest in training programs to grow the critical mass of skilled technical staff.

9 Small inhibitory ribonucleic acid.
10 The ability to make a 10-fold greater number of antibodies in one-tenth the time at one tenth the cost allows new HTS applications of this technology in research and drug development (approximately 25% of all new drugs in clinical trials in the United States are monoclonal antibodies).

Figure F



One of the other major challenges is one of culture. Within BPA and APN, attitudes to infrastructure accessibility and integration have been well embraced. However, work still needs to be done to promote to both researchers as well as funding agencies within the broader community the merits of accessing centralised, high quality integrated infrastructure. This will be best achieved by both promoting the efficiencies and quality of research output achievable from these enabling technologies as well as highlighting examples of success (see case studies next page).

A particular area requiring application of this capability is the forensic sciences, where forensic biology issues are perhaps not well enough recognised by health and biomedical professionals. Biomolecular profiling and rapid field analysis are key to the next generation of biological, analytical and informatic solutions for forensics.

Requirements

Infrastructure

Specific areas of infrastructure need include:

- Investment in rapid high throughput DNA sequencing and protein/antibody arrays;
- Implementation and extension of overarching “federated” bioinformatics, perhaps modelled on the Victorian BioGrid concept at a national level. This would establish true biological systems integration, linkage with genomic and molecular data as well as other large data collections, linkage with other capabilities, and inclusion of medical and health informatics;
- Use of siRNA and small molecule (chemical biology) libraries to probe cellular responses and build up a systems biology model of different cell types (e.g. neuronal, epidermal, liver, etc.). These models can then be used by all researchers to make predictions as to which proteins are involved in different disease states;
- Inclusion of high throughput screening of small molecules and fragment-based screening together with the infrastructure needs for medicinal chemistry of promising leads flowing from the use of these approaches;
- Given the applications and cost of nuclear magnetic resonance (NMR) and mass spectrometry (MS) and their importance to structural biology and metabolomics, there appears to be a need for improved NMR and MS facilities provided that national collaborative needs can be addressed. This is best addressed through the Characterisation capability, as is the need for high throughput imaging;
- Further enhancement of the APN capability to consolidate Australia’s current high level of international engagement;
- Access to biobanks and large scale sequence data (see the Population and Biological Health Data Network capability); and
- A sustainable investment strategy across broader investments and monitoring of capability uptake and investment where demand exceeds capability.

Support

Areas include:

- Support for the promotion and showcasing of capabilities to the broader Australian research community;
- Australian funding agencies to appropriately fund the costs of access to capabilities;
- Training programs and career structure for skilled technical staff; and
- Further scoping to consider the needs of biological forensics. Possible requirements may include specialist ultra clean laboratories, separate analytical facilities and a network for interested researchers.

Case Studies

The very broad range of applications enabled by the Integrated Biological Discovery platform is illustrated by the examples that follow.

Genomics

Genomics can be used to identify and develop new sources of biofuels, including grasses and trees that can be grown on non-agricultural lands, and bacteria that can easily convert cellulose-rich plant fibres into useful biofuels. High-density single nucleotide polymorphism (SNP) chips are being used to predict predisposition to breast, colon, prostate and other cancers and pave the way toward personalised medicine through individual pharmacogenomic analysis. Perhaps one of the most exciting genomic developments is metagenomics, where the genetic content of material recovered from environmental samples can be analysed and compared to reference databases to determine the impact of environmental factors such as climate change.

Proteomics

As drugs such as interferon and erythropoietin come off patent, there will be a rush to produce generic drugs that are as safe and effective as the named brands. Proteomics Australia (PA) is one of only a handful of organisations – and the only one in the Asia-Pacific region – that is providing the necessary, and potentially lucrative, service that ensures these new generic drugs are the same as the branded ones they claim to replace.

Other examples of proteomic applications in Australia include: elucidation of the molecular mechanisms of resistance to childhood cancer drug treatment and colorectal cancer chemoresistance biomarkers; determination of the Australian wheat crop storage proteins and development of assays for glutamine content; development and commercialisation of HTS cell signaling pathways with multinational Perkin Elmer; and a large collaborative research program with the multinational pharmaceutical company Pfizer on a new approach for plasma biomarker discovery.

Metabolomics

Research being undertaken by the Australian wine industry combines metabolomics output with genomic screening technologies to identify the genes and metabolic pathways behind desirable traits. Already a significant amount of variation between the wine yeasts and their laboratory counterparts has been identified, including several regions of DNA that are only found in the wine yeasts and this data is being correlated with different metabolic profiles.

Forensic Science

Current approaches to forensic biology are mainly commercial systems and address identification but not broader forensic requirements. The underpinning science is mature but as patents run out, next generation solutions will emerge based on whole genome information. The demands on forensic science will continue to grow with a need for rapid field based testing and laboratory approaches capable of delivering quicker answers with more challenging trace and degraded samples.

To ensure Australia has a stake in developing the next generation of biological analytical and informatic solutions for forensic science, forensic biologists need to work with other sectors of the molecular biology and biomedical community as the underpinning scientific and technological developments will emerge from these fields. This would include science, technology, and informatics to meet the exacting analytical and legal standards for forensic application.

Translating Health Discovery Into Clinical Application

Description

Drug therapy underpins the treatment of most human diseases and there is unmet demand for novel and improved therapeutic agents, including both small molecules and biologics. New drug discovery is the subject of considerable research endeavour in Australia while cell therapy and the development of nanomedicines are significant emerging areas. However, evidence in support of efficacy, safety and other properties is critical prior to the successful clinical development of new therapeutic agents. Not only is the availability of coordinated pre-clinical capabilities required but also an improved capacity to perform clinical trials and participate in large-scale studies.

Moreover, successful translation of Australian drug discoveries into effective medicines requires knowledge and skills in translational sciences for the effective linkage of required elements that might include: identifying bioactive molecules (using high throughput screening); developing credible drug candidates using medicinal chemistry and the skills of lead optimisation; cross-disciplinary bioinformatics; access to unique clinical and non-clinical biological samples (biobanks); appropriate animal models of disease; multimodal imaging; scaling up manufacture of potential therapeutics for pre-clinical and clinical testing; and access to defined clinical populations.

Strategic Impact

Australia has strengths in health and medical research but frequently lacks the capability to move from the laboratory to the clinic. Although several academic institutions and commercial operations provide 'specialist' pre-clinical testing, integration and the breadth of capability needed to fully realise the economic potential of drug discovery research in Australia are limited. Existing capabilities are generally geographically dispersed and frequently dedicated to the needs of specific organisations. Services provided on a fee-for-service basis are often too expensive for academic institutions. This is not surprising given the scale and complexity of therapeutic development.

Consequently, translation of basic research fails to occur or drug discovery intellectual property (IP) is sold to overseas interests too early and for too little value. Demonstration that a compound has promising pharmacological activity, favourable ADME[11] characteristics, and acceptable toxicity facilitates its progression along the pharmaceutical 'value chain'. Even greater benefit comes with successful clinical development. Appropriate support structures to foster Phase I and Phase II clinical trial activity will result in improved financial returns to academic institutions and industry.

11 Absorption, distribution, metabolism and excretion (ADME).

Challenges and Assumptions

This capability, as articulated in the 2006 Roadmap[12], was not funded yet much of the infrastructure to prosecute drug discovery is already in place, the legacy of institutional investment. What is lacking is operational support that would improve accessibility of existing infrastructure for all users. Consultation in the community at that time identified that a modest investment in network infrastructure could potentially provide a large increase in returns.

Although there is expertise in many of the areas that underpin pre-clinical testing, there are also areas of weakness and the possibility remains that a national, centralised facility may have advantages. This is particularly true in pre-clinical toxicology, especially relating to small and large animal facilities. A related issue is whether all of the biomarker and animal disease models necessary to support a comprehensive pre-clinical testing capability can be provided in Australia.

Figure G

There is a pressing need to understand the behaviour of novel drugs, drug delivery systems, and sensors in animal models of disease. The availability of multimodal imaging technology to large animal researchers would markedly enhance the level of functional information of tissues through monitoring metabolism under various experimental conditions and progress the translation of this technology to clinical services.

Clearly, a pre-clinical capability is of little relevance in the absence of a viable small molecule/biologics discovery program. Many opportunities are lost at present, and the road-block is at the drug design stage, rather than at the later stage of 'formal pre-clinical evaluation' using GMP[13] facilities (see Integrated Biological Discovery for relevant high throughput screening and medicinal chemistry).

12 The capability focused on integrating pre-clinical components and has been updated to include gaps in the pathway at the drug design level through to clinical trial capacity and incorporates those components of Biotechnology Products that relate to manufacture of biologics and cells for therapy.

13 cGMP is the Code for Good Manufacturing Practice.

There is also a major movement in biology to what is being termed nanomedicine that has special infrastructure needs that may need to be considered under the Fabrication capability. Regarding biologics and cells for human transplant, the focus to date under the NCRIS program has been on pre-cGMP research as well as cGMP process development and scaling up for pre-clinical testing and phase 1 and 2 clinical trials.

Expertise in many areas and across disciplines needs to be addressed as it is not just 'facilities' but the development of an improved evidence and skills base to underpin effective translation that is lacking. For example in relation to improved capability in imaging - the limitation may not be resourcing an imaging modality but rather access to expertise and capabilities in labelling of drug candidates and nanomedicines such that they might be effectively imaged.

Requirements

Infrastructure

Requirements include:

- An integrated network of preclinical testing facilities including ADME, animal disease models, biomarkers, and toxicity testing controlled by an overarching body that addresses issues of governance, benchmarking and accessibility is needed. In particular, there is a lack of facilities for toxicology and of expertise in designing toxicology experiments;
- Access to multimodal imaging technologies to allow monitoring of metabolism under various experimental conditions, potentially through an expanded Large Animal Research and Imaging Facility[14]. Consideration is needed for the further development of integrated imaging facilities in small and large animal and human clinical trial facilities;
- To enhance the capacity to perform clinical trials, a dispersed model has been suggested centred on groups with disease and trial specific expertise. The infrastructure required is support for clinical trials networks, such as research staff, statistics services, tissue banks and information systems to support randomisation, data capture and analysis; and
- Continuation of existing NCRIS-funded infrastructure for large scale mammalian and non-mammalian cell based manufacture of recombinant proteins as potential therapeutics, including the supply of therapeutic monoclonal antibodies in adequate quantities for evaluation, and of human cells or cellular based products for transplant. Possible enhancements relating to emerging cell therapies may be to support growth of stem cells, mature cells, cell lines and animal cells with links to bone marrow and cord blood facilities.

Consideration should also be given to establishing:

- A national small molecule repository and a national screening network to identify small molecule drug candidates;
- National large animal preclinical and testing facility;
- An increased capacity in high quality animal pathology and phenotyping; and
- The infrastructure needs for designing, producing, characterising and testing nanoscale products of biological and chemical research for application in medicine. Links with the Fabrication capability should be promoted.

Support

The convergence of high-end computing, computational biology and molecular sciences has implications for drug research and other translation. There is a need to review the national capability in overarching or cross discipline bioinformatics to determine if the current support and capabilities are adequate.

Enhanced resourcing of knowledge and skills in translational sciences is needed - the infrastructure support is required not only to provide facilities and networks, but rather to provide infrastructure to support an improved knowledge base.

There is a need for the National Health and Medical Research Council (NHMRC) and the Therapeutic Goods Authority (TGA) to be involved. For example, preclinical interventions are regulated by the TGA, with different requirements according to its risk classifications.

To take maximum advantage of large-scale clinical trials, access to defined clinical populations, Australia's growth and research efforts in stem cell research and access to unique clinical and non-clinical biological samples, there is a clear need to invest nationally in large scale biobanking (see Population and Biological Health Data Network).

14 A node of the National Imaging Facility was established under the NCRIS program. See the Characterisation capability in this Roadmap for more detail.

Population and Biological Health Data Network

Description

The capacity for researchers to access an integrated, national resource of population health and biological data will contribute to identifying the causes of disease in individuals and populations, and to developing new diagnostic, preventive and therapeutic interventions.

This will require access to biological specimens and the biochemical, genetic and other information obtained from these specimens, detailed information about health and lifestyle factors derived from cohort studies and clinical research, and information from key administrative health datasets including those relating to Medicare Benefits Schedule (MBS) and Pharmaceutical Benefits Scheme (PBS) services, hospital inpatient episodes, diseases and deaths. In developing this capability, it is critical to consider the complex issues related to privacy of health datasets.

The ability to link data and develop models that cross organisations, sectors and disciplines will make a powerful contribution to understanding and controlling major common illnesses.

Strategic Impact

An integrated national resource of population health and biological data will be a significant contributor to understanding and controlling major illnesses, including cardiovascular diseases, diabetes and other metabolic disorders, cancers, diseases of the nervous system, infectious diseases and diseases of the immune system. It is highly likely that some of the lesser illnesses will also be amenable to analysis and therefore better treatment.

Linkage of key administrative health datasets, data on hospital inpatient episodes, diseases and deaths, and exchanging and delivering these data to researchers in a secure manner is an important first step in harnessing Australia's major population-based collections of health data for research and creating the largest national health data linkage system in the world.

Building on a linkage capability, an expansion of the national resource of health data beyond those that are collected routinely in administrative systems and in a relatively small number of statutory registers (cancer, deaths) is required to maximise the value of the national data linkage system and dramatically increase its potential for "discovery" research. This would incorporate two types of data:

» Detailed data about socio-demographic factors, lifestyle and health from cohort studies and clinical research. Large volumes of data from these studies already exist, but are scattered across institutions; and

» Biological specimens and the information derived from them. This involves the development of large-scale biobanks to house collections of samples such as cells, tissues, blood or DNA, that are associated with personal and health information of their donors and can play an important role in determining the role of genetic factors in the causation of diseases.

Challenges and Assumptions

The NCRIS-funded Population Health Research Network (PHRN) currently being established has support from all state and territory governments and key research institutions, and will implement a nation-wide health data linkage structure that will provide the means to multiply the utility of datasets in population health. The establishment of this network will catalyse coordination and interoperability of secure health data linkage services that preserve the privacy of individuals and allow researchers across the jurisdictions to access Australia's 'world's-best' population-based health and health-service datasets.

The establishment of the PHRN provides an important base on which to address issues related to the current fragmented arrangements for the collection and holding of the existing resources which at present have limited researcher access and use. These include large volumes of data from cohort studies, clinical research and tissue banks, as well as various tissue banks themselves.

The cost and complexity of setting up facilities for storage and retrieval of biological specimens has limited the growth, development and application of findings from related research in Australia. Creating cohesion from these diverse arrangements and reshaping behaviours around data sharing will be a challenge. Addressing community concerns about privacy and ethics will be a key step, as will integration and coordination with eHealth strategies under development by federal, state and territory health departments across Australia.

The successful implementation of the PHRN requires several critical enablers which are also crucial to a broader integrated population health and biological data network, including:

» Robust ethical frameworks and mechanisms for community engagement;

» Robust mechanisms for protection of privacy and confidentiality;

» Appropriate arrangements regarding intellectual property and its commercialisation;

» Cooperative and constructive participation of data custodians, including government departments, universities and research institutes;

» Secure and reliable ICT infrastructure; and

» Availability of research and technical staff with the relevant range of skills.

Expansion of this capability to encompass key data sources and collections, as well as the mechanisms for storing, exchanging and linking data, will require additional and different support, including:

» A framework and sound business model for biobanking infrastructure that also addresses how it will be accessed and costed; and

» Research and technical staff with skills in biostatistics, genetic epidemiology and bioinformatics.

Requirements

Infrastructure

In order to build the national integrated population health and biological data network, the following infrastructure is required:

» Dedicated ICT infrastructure to support the access, analysis, management and storage of large, complex datasets;

» Infrastructure to support the ongoing maintenance of key cohort and clinical studies of national significance (participant tracking and follow-up, ongoing data collection, data management); and

» A coordinated network of physical facilities for secure storage, retrieval, management and use of biological samples of various types (blood, cells, tissues, organs). This might take the form of networked facilities specialising in specific types of sample, and/or several more general facilities at strategic locations around the country.

Support

Areas of support required include:

» Research workforce capacity building and training initiatives;

» Linkages with other health capabilities; and

» eResearch infrastructure that provides the critical links to other enabling technologies, which in turn feed into datasets across all biological systems, population health databases, imaging and other phenotypic screens databases.

Frontier Science and Technology

Contextual Framework

Cutting-edge pure and applied research in the physical sciences plays a central role in understanding our universe, in the development of innovative technologies that underpin a wide range of research activities in other fields, as well as in the growth and establishment of new industries.

The breadth of this science is immense – it ranges from studies into the fundamental nature of the atom, through to the study of the universe; from revealing and understanding the structure and function of matter at the micro/nano/pico levels, through to the creation of new materials and devices. The range of technologies that are both used and developed is equally varied and vast. These have great application beyond their origins in an increasingly large number of other research areas including the life sciences, and everyday uses in areas such as health and environmental services.

The facilities, equipment and instruments required to undertake this research are complex, often large and expensive to acquire and operate; specialist skills and supporting infrastructure such as advanced information and communications technology (ICT) are critical to their ongoing operation, maintenance and further development.

Research Capabilities

Through the NCRIS program, investments in the priority capabilities Characterisation, Fabrication and Astronomy have enabled the establishment of, and enhanced access to, a range of facilities, instruments and expertise that are supporting important and world-leading research.

The continued need across these capabilities, to build on and enhance the investments already made, is confirmed in this Roadmap.

The importance of science and technology to sustainable energy discovery and production is recognised, although further scoping is required to develop a strategic approach to any investments in research infrastructure in this area. Similarly, strategic planning for infrastructure investment in heavy ion accelerators requires further development.

An area of some focus during the development of this Roadmap was infrastructure to support research into ICT. However, significantly more scoping is needed to articulate a distinct capability or element within a capability to support ICT research. Such scoping should include the future needs of other research capabilities.

Characterisation

Description

Facilities to characterise the physical, chemical and structural properties and functions of matter (both living and non-living), and determine how those properties change over time or under stress, are essential tools for research activities across the physical sciences, life sciences and engineering.

There is a wide range of characterisation techniques used, which can be broadly classed as different types of probes that use photons and electrons (e.g. optical and electron microscopy), neutrons (e.g. neutron scattering), X-rays (as provided, for example, through synchrotrons) or magnetism (such as magnetic resonance imaging (MRI)) to reveal the attributes of materials, molecules and tissues, with varying degrees of resolution and scale, and in different applications and experimental conditions. Increasingly, a combination of techniques is being used to reveal a level of information far greater than the individual instrument can provide. Additionally, measurement in real time at high resolution is rapidly becoming available in many areas and promises to be a powerful approach in many fields.

Whilst the availability of a variety of characterisation techniques is vital, the complexity, scale and expense associated with the various techniques poses a number of challenges for the planning and prioritisation of investment in this capability.

Strategic Impact

Advanced characterisation techniques play a key role in innovation and research across the physical, life and environmental sciences. They underpin the conduct of many fundamental research efforts and the development of new and emerging technologies such as nanotechnology. Some examples include:

- The use of protein crystallography, available through synchrotron facilities, to determine the chemical structure of biologically significant molecules (such as proteins) to aid in the design of new drugs;
- The use of spectroscopy to study the surface properties of new materials in order to determine how they wear or corrode in hostile environments, such as the human body; and
- The use of fluorescence microscopy to study the structure-function relationships in naturally occurring organisms such as corals in order to understand how to protect them from damage and exploit them for new applications (e.g. artificial scaffolds for bone growth).

In addition to providing facilities that enable excellent research, advanced characterisation capabilities also stimulate research into the development of emerging techniques themselves. Australia has a strong track record of success in this regard, and a significant level of expertise that is able to facilitate the subsequent application of new techniques to various research and development (R&D) activities.

A large number of researchers working across many disciplines, institutions and industry require ready access to a suite of world-class characterisation tools and techniques in order to remain competitive internationally and contribute to the delivery of research outcomes relevant to health, manufacturing, engineering and the environment. Access to such state-of-the-art facilities also enables participation in international collaborations through which Australia leverages additional knowledge and equipment access.

Challenges and Assumptions

A number of considerations and issues need to be taken into account with regard to planning additional investment in characterisation.

The variety of techniques needed by researchers

- There is a large range of characterisation techniques currently available and emerging. Key challenges are to determine the level of user demand for the various techniques, to assess the most appropriate approaches for planning the delivery, and to determine the level of investment required. Other aspects include the types of application, how often the technology is likely to be 'refreshed', and what relevance emerging techniques have to Australian researchers. The level of development of commercial instruments is also an important consideration.

The scale of the facilities that are required to provide these techniques

- Whilst recognising that some characterisation instruments can be operated at an institutional level, many techniques are expensive, require specialist technical support and are best operated as centralised or networked facilities that are open to all researchers. This model has been has been implemented through the NCRIS program with regard to microscopy (through the Australian Microscopy and Microanalysis Research Facility [AMMRF]) and imaging (through the National Imaging Facility), and provides a basis for future provision of advanced characterisation research services nationally.

Figure H

- For techniques such as neutron scattering and X-rays, large-scale facilities such as the Australian Synchrotron and the Open Pool Australian Lightwater (OPAL) research reactor are increasingly important as the main sources of high intensity beams. As these major research facilities become fully operational, the suite of beamlines and associated instrumentation they provide will attract a growing number of researchers and, moreover, will greatly facilitate and encourage collaborative efforts amongst researchers both within Australia and internationally. The capital investment in these 'landmark' facilities is significant, and a central issue is the long-term support and funding mechanisms in terms of both facility enhancements and upgrades (such as additional beamlines) and operating costs (including skilled technical staff) in order to provide ongoing and additional capabilities to researchers.

Associated issues around the cost of operation and provision of skilled technical support

- The cost of operating and maintaining sophisticated instruments can be significant, and must be considered as part of the overall infrastructure budget. This is a particular issue for large facilities, but is equally important for networked facilities.
- Skilled staff to support operations, provide expertise in the application of techniques, develop new experimental approaches and techniques, and knowledge of future trends are essential to the success of service-oriented delivery of characterisation techniques.

Requirements

Infrastructure

High-level Microscopy and Microanalysis

Demand for existing techniques is high and is expected to increase as exploration of nano and microscale phenomena by researchers from an increasing range of backgrounds and disciplines increases, in part due to the investment from the initial NCRIS funding as well as new, exciting techniques that will become available. Delivery through a shared facility with ready access for all researchers is preferred, building on the AMMRF service model that provides a range of techniques, expertise and geographical coverage. Future investments should be guided by strategic planning based on user-demand and usage.

Infrastructure requirements may include: increased capacity and continued support for existing techniques; new microscopy and optical spectroscopy techniques (including multi-mode instruments); and consideration of new national capabilities including nanometrology and electromagnetic measurement techniques.

Neutron Scattering

NCRIS funding has enabled the establishment of the National Deuteration Facility at the OPAL research reactor. Additional beamline techniques at OPAL should be considered in the context of an overall strategic plan for this landmark facility that examines usage, user demand, available instrumentation options, facility upgrades and long-term operating requirements.

X-Ray Techniques

NCRIS funding has supported the completion of the initial suite of beamlines at the Australian Synchrotron. As with the OPAL research reactor, consideration of additional beamlines at the Australian Synchrotron should be considered within the context of an overall strategic plan for this landmark facility. This strategic plan should be based on user demand and also consider options for access to overseas synchrotrons for additional capacity and techniques not available at the Australian Synchrotron.

Imaging

There is an increasing demand for powerful imaging techniques, including in health and medical research. Future imaging investments should build on the National Imaging Facility, established under the NCRIS program, which has catalysed a national collaborative approach that builds on previous individual research strengths, allows complementary approaches to be combined, shares expertise and develops new techniques.

Future areas of investment may include: increased capacity and ongoing support of existing techniques; Magnetic Resonance Imaging (MRI) techniques; and inclusion of NMR spectroscopy. It is recognised that NMR techniques have wider application and benefit beyond imaging, and consideration may be given to NMR being a separate sub-element of Characterisation.

Support

Support for the Characterisation Council, established under the NCRIS program to provide a mechanism for determining the overall strategic direction for the characterisation capability including advice on future areas of investment, should be continued.

Where possible, collaborative links to other capabilities including Fabrication, Integrated Biological Discovery, Translating Health Discovery, Australian Continent, and Networked Biosecurity should be enhanced. This may be achieved through people and ICT networks, cross-research infrastructure roundtables and promotion, and research collaborations and projects.

ICT-enabled support includes:

- High-end high performance computing requirements will significantly increase as large datasets become available and tools and algorithms become more accessible. Specialised analysis of 3D, 4D and 5D datasets is foreseen. Curation of datasets and specialised eResearch-enabled data analysis tools are needed.
- Access to visualisation tools is needed to manipulate large multi-dimensional datasets from instruments. Collaborative tools such as web based collaboration spaces, videoconferencing and customised workflows from specialised facilities are also needed.
- Network capability is needed to support transfer of large datasets from instruments, as well as support remote access to facilities and instruments.

Fabrication

Description

The capacity to produce industrial trial quantities of materials, fabricate product components, and rapidly produce prototypes is critical to Australia's ability to undertake high quality research that drives innovation, and to progress research outcomes to market.

Facilities for micro and nano fabrication enable researchers to better study the structures and properties of new classes of materials, progress the development of demonstration products and processes, and integrate and package components for a wide range of devices. These facilities encompass cutting-edge equipment and cleanrooms that provide the capability to fabricate, process, manipulate and synthesise materials and devices.

Strategic Impact

Australia has a strong track record in science and engineering research in fabrication areas such as advanced materials, photonics and biomaterials. The requirement for access to locally available, modern facilities and the expert technical staff needed to maintain and operate them is essential to the continued delivery of research outcomes in these areas, and the commercialisation of these outcomes.

Nanotechnology is an emerging industry sector that is seeing a rapid expansion, as outcomes from research are transformed into a range of applications in areas such as health, aerospace, automotive and telecommunications.

Underpinning the broad range of research activities associated with nano- and micro-technology is the infrastructure and facilities for the processing of materials and fabrication of structures that have application in sensors, medical devices, renewable energy, nanophotonics and nanoelectronics.

Given that prototype development often involves multiple iterations in design and testing phases, a coherent, nationally coordinated research infrastructure is required that provides access to facilities be they local or international, and also facilitates collaboration and linkages with industry.

Challenges and Assumptions

The investment under the NCRIS program in the Australian National Fabrication Facility (ANFF) has enabled the establishment of a national network of nodes that builds on existing facilities and centres of expertise and which provides open access for researchers to a suite of state-of-the-art fabrication capabilities in advanced materials, bio- and chemo-based products, and microelectronics, photonics and optoelectronics. Through the creation of the ANFF, the delivery of various fabrication capabilities is better coordinated and supported, and it is generally well positioned to meet the current fabrication needs of Australian researchers.

The underpinning nature of fabrication to a number of research areas and applications necessitates the ongoing assessment of the level of capacity available to meet the demands of researchers nationally, and the types of equipment and processes that are needed to support leading-edge research and pre-industrialisation process development. Training and attracting skilled staff to operate and maintain equipment is also critical.

Linkages with other capabilities, in particular with techniques provided through Characterisation, offer important opportunities to build a comprehensive research and development capacity in areas such as biomaterials, and should be strengthened where possible. An increased focus on integrated, systems approaches to research in areas such as nanotechnology and biotechnology warrants future consideration of the benefits and opportunities that may arise through co-location of certain fabrication facilities with capabilities in characterisation, health discovery and translation, and sustainable energy. Such arrangements can provide opportunities to increase the potential for cross-disciplinary collaboration and synergies between researchers, reveal new areas for investigation and speed up the development of industrial applications.

Requirements

Infrastructure

The requirement for enhanced pre-pilot process lines that are upwardly compatible with future industrial-scale manufacture is considered to be particularly important in order to maximise engagement with Australian industry. This should build on and/or link to the intermediate-scale capabilities currently available or under development through the ANFF.

Within the advanced materials area, there is potential need for a nanomaterials 'foundry' capable of large-scale manufacture of carbon nanotube based materials, metallic or ceramic nanostructures and nanostructured polymeric-inorganic composites. There is a requirement for specialised fabrication capabilities for materials development relevant to sensors and renewable energy applications including photovoltaics, fuel cells and fusion.

Figure I

Further investment in cross-disciplinary fabrication and integration capabilities, in particular nano-material fabrication and the bio- and chemo-manipulation of nanostructures, will be central to supporting fully integrated approaches to the development process, from materials selection and creation through to pilot-scale manufacturing. Nano-material manufacturing facilities relevant to medical and sensing areas should also be enhanced. Support for chemical biotechnology, for example the manufacture of biopolymers and new bioconversion techniques, should also be considered.

The availability of conveniently accessible ion implantation tools for use in photonic and electronic materials growth and semiconductor fabrication has also been identified.

Support

There has been limited identification of the ICT needed to support this capability, and further scoping of the ICT needs would be warranted. Likely areas of need include: high performance computing to support complex modelling of nanostructures and nanomaterials; 3D visualisation tools; and data management needs that are not explicit, but appear to be particularly related to the metadata of digital output.

A potential need to develop research precincts, and co-location of facilities and expertise to capitalise on current investments and enable integration with other capabilities may have bearing on the further development of the Fabrication capability. In particular, a need to co-locate fabrication facilities with biological facilities and characterisation equipment to maintain process integrity has been identified.

Cross-linkages with other capabilities including Characterisation, Astronomy, Sustainable Energy and Translating Health Discovery should also be developed.

Optical and Radio Astronomy

Description

Through astronomy we are beginning to understand the emergence of life within the tapestry of planets, stars, dust clouds and galaxies of our universe, and how this emergence is linked to the physical laws governing the origin, evolution and final fate of the universe itself.

Fundamental to modern research in astronomy are the large, highly sophisticated and increasingly international facilities (telescopes) that cover the optical, infrared and radio wavelengths of the electromagnetic spectrum.

In order to produce world-class research and innovation, Australian astronomical researchers must have access to the current and next generation of optical and radio telescopes. These include 8-metre class telescopes (e.g. the Gemini Observatory, with one telescope in Hawaii and one in Chile), the proposed Square Kilometre Array radio telescope, and future optical facilities such as the proposed Giant Magellan Telescope (GMT) and PILOT Antarctic telescope.

Strategic Impact

Astronomy is one of Australia's highest impact sciences. Australian astronomers have played a leading role 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.

Figure J

Development of infrastructure for astronomy, such as the instruments that are used on national and international telescopes, and the state-of-the-art data acquisition systems that are required to process massive amounts of data across wide bandwidths, involves leading-edge research and continues to provide technological spin-offs in areas such as electronics, engineering, and information and communications technology.

Australia's bid to host the Square Kilometre Array (SKA) is providing a significant increase in awareness regarding Australia's astronomy capabilities, and is highlighting the potential benefits of establishing such a landmark facility in Australia to the wider research community, industry and the public in general.

Challenges and Assumptions

Collaboration amongst the Australian astronomy community is highly developed, and is in many ways necessitated by the size of the facilities required and their global nature. The *Australian Astronomy Decadal Plan 2006-2015* is evidence of this – it presents the community's strategic vision for Australian astronomy, and includes its priorities for infrastructure. The establishment under the NCRIS program of Astronomy Australia Limited (AAL) as the peak entity for channelling Australia's investment in national and international astronomical facilities further demonstrates the astronomy community's ability to plan and coordinate activities relating to current and future investments.

A significant challenge for the astronomy community is the commitment of support to long-term engagement and participation in international astronomy projects, both within Australia (e.g. SKA) and overseas (e.g. Gemini and GMT). This is essential to achieving a suitable level of access to current and future facilities, and enabling opportunities for technology developments relating to major telescope instrumentation programs. The scale of investment and the long development timelines necessitate careful consideration and prioritisation of options for future telescope projects. Ideally, a rolling program of funding and review is required, and recognition that funding through programs such as NCRIS may be the precursor to a landmark infrastructure proposal. A further issue for the community relates to the balance within and between radio and optical facilities.

National facilities such as the Australian National Telescope Facility and the Anglo-Australian Observatory play an important national and international role in supporting astronomy research and training. The needs of these facilities should be considered in the overall context of future national astronomy infrastructure requirements.

Requirements

Infrastructure

A coherent and complementary mix of optical and radio facilities is needed to support a vibrant and competitive research community. Specific requirements will include:

- Access to at least a 20% share of an 8-metre class telescope. Australia is already a partner in the international Gemini Observatory, but access to other international 8-metre class telescopes is also an option;
- Support for the Australian SKA Pathfinder (ASKAP) project and Phase 1 of the SKA. The nature of this infrastructure investment will be guided by the progress and outcomes of the international SKA process. If Australia is successful in its bid to host the SKA, the ASKAP will provide a key stepping stone to the development of a landmark infrastructure proposal; and
- Participation in the design and development phases of future optical telescopes, specifically the GMT and the PILOT Antarctic telescope. This will allow evaluation of options and positioning for significant shares in access to these telescopes and involvement in instrumentation projects.

Support

Key areas of support for Australia's astronomy capabilities relate to governance, ICT and skills:

- Continued support is needed for national coordination mechanisms, in particular AAL and advisory structures such as the Australian SKA Coordination Committee, and for international engagement.
- ICT requirements include: ongoing and developing demand for high performance computing, envisaged to be in multi-petaflop infrastructure; data needs including discovery, sharing, integration, storage and curation of long-term, complex and increasingly large datasets; needs for computational modelling and simulation tools, for real-time visualisation and visualisation of complex data; and network needs which include backbone connectivity for data transfer and connection to instruments from very remote locations among others. In addition to the initiatives noted already, work towards an International Virtual Observatory will increase demand around networks and data.
- Skilled technical personnel to support operations and instrumentation programs are essential.
- Adequate funding support for accessing overseas facilities is needed through enhancements to programs such as the Access to Major Research Facilities program, or by other means.
- Enhanced cross-linkages with the Fabrication capability are required to support developments in areas such as astrophotonics and microelectronics relevant to astronomy instrumentation programs.

A Sustainable Energy Future

Description

A holistic view is required to set Australia on a path to a sustainable energy future. In the transition from a dependence on fossil fuels for energy, it is important to recognise the long time-scales of energy development and deployment (a matter of decades). A cohesive energy system will therefore require a mix of technologies to be developed and implemented to achieve sustainable energy goals[15]. The approach may include uptake of clean coal technologies to reduce greenhouse gas emissions, supported by increasing adoption of sustainable sources of energy, and complemented with technologies that address carbon sequestration as well as energy conversion, efficiency, storage and distribution.

Australia is able to tap a number of significant sustainable energy sources that could begin to make an immediate contribution to base-load generation including solar (photovoltaic, solar thermal), wind, geothermal and ocean (wave/tidal/current) power. Next generation biofuels, battery and fuel cell technologies are some of the energy options for transport and field use under development. As part of the mix, a truly long-term solution for large-scale, non-polluting energy supply may eventually come from nuclear fusion. Closer to implementation as a large scale energy supply option is generation using nuclear fission, but the opportunity to develop Australia's significant uranium reserves for power generation brings with it the issue of radioactive waste management.

Strategic Impact

Australia's energy future underpins future national prosperity. The three fundamental pillars that will need to be tackled simultaneously, in such a way that impacts occur at the local, regional and global levels, are:

- energy security;
- low emissions energy; and
- the economic impacts that include the opportunity for significant wealth generation.

The International Energy Agency predicts an increase in world energy needs of almost 60% by 2030. Despite Australia's abundant and relatively low-cost coal and gas resources, the continued use and national economic contribution of coal is threatened by increasing pressure to reduce greenhouse gas emissions from coal-based electricity generation. This risk can be mitigated through adoption of clean coal technologies and remains an immediate priority.

However, sustainable energy contribution and eventual replacement of coal-based technologies is inevitable. Concerns surrounding the sustainability of fossil fuels for power generation have promoted intense interest in alternative forms of energy. Australia has long incorporated hydroelectricity into its power supply but further uptake of sustainable energy is necessary to achieve reduced emission targets and provide energy security.

Though potentially an energy solution of global proportions, fusion is still in experimental phase and requires concerted international collaboration, investment and co-operation to bring to commercial reality. The technology has recently entered the pre-prototype power plant stage through the $16 billion International Thermonuclear Experimental Reactor (ITER) being constructed in France and funded by a consortium of seven countries and groups including Japan, Russia, China, India, South Korea, the European Union, and the US. If successful, a virtually limitless supply of clean, safe energy would be created from deuterium which is naturally abundant in water.

Challenges and Assumptions

Australia has a well established coal industry and vested interest in its continuation, but there is a requirement to reduce carbon emissions from coal usage in the near term. A number of programs funded at federal and state government level are supporting developments in large-scale greenhouse gas abatement technologies, coal gasification and development of synthetic fuels, and R&D in Australia in gas to liquids and coal to liquids is currently increasing.

Coupled with the clean coal strategy is the need to support sustainable energy alternatives. In recent years, a number of initiatives have arisen to address energy and emission issues relevant to a sustainable energy landscape, and a major challenge will be to harness these various research efforts effectively. Some examples include:

- The Centre for Energy and Greenhouse Technologies which invests in emerging sustainable energy technologies that reduce net greenhouse gas emissions;
- Australian Government support for solar energy initiatives, with $100 million funding provided to advance solar thermal and photovoltaics;
- Development of a geothermal energy roadmap, intended as a guide to the implementation of this important sustainable energy resource; and
- At least 15 major carbon dioxide capture and/or storage demonstration projects either under way or in the advanced planning stage in Australia.

15 The Australian Government has a policy for 20% of electricity to come from renewable energy by 2020 and a reduction in our greenhouse emissions by 60% over the next 40 years.

Through the NCRIS program, support has been provided for research into next-generation liquid biofuels through funding for the development of pilot-scale facilities for production of ethanol from lignocellulose and biodiesel from micro-algae. Further investments in other forms of bioenergy research infrastructure and possibly a broader spectrum of alternative energy technologies are warranted; however, issues related to the scale of facilities required and international developments must be considered.

Despite its grand scale and long timeframe, it is possible to include fusion power development in Australia's sustainable energy future. Support for research related to fusion power development is likely to require consideration of investments in local capabilities, including experimental facilities and skills development, and participation in international activities such as ITER.

Requirements

Infrastructure

Given the broad nature and scale of energy-related research and development, infrastructure to support research into specific processes and related activities (such as fabrication of specialist materials) ranges from laboratory-scale equipment to pre-pilot facilities capable of 'scaling-up' processes, through to larger-scale demonstration or prototype facilities that may lead to commercial and industrial development.

A strategic planning process is required to develop a coherent, coordinated approach to the type and level of investment in infrastructure necessary to support sustainable energy research and development across both fossil and renewable sources. This should take into account the current policy framework, past, current and planned investments and initiatives, areas of research strength, and the international energy research environment.

Support

Technology developments in energy production will benefit from linkages to investments in frontier science and technology capabilities such as Fabrication, Characterisation and those related to biotechnology applications including biofuels and higher value products.

Similarly, knowledge of environmental systems and changes to these systems, and understanding the social drivers and behaviours that relate to energy use, are essential to informing decisions regarding a sustainable energy future. This demands strong links with capabilities in environment and social sciences.

There is a recognised need for research and commercialisation connections with industry and business to support existing and emerging strengths.

Heavy Ion Accelerators

Description

Heavy ion accelerators produce high energy ion beams which support a range of research activities, from fundamental studies of the quantum nature and interactions of atomic nuclei, to broad-ranging applications in materials science, resource exploration and management, environmental science, anthropology and archaeology.

Ion accelerators are large-scale, highly sophisticated facilities comprising the core accelerator, beam lines and experimental end-stations, and ancillary equipment. Australia has built a significant capability around a number of centres for accelerator-based research which are internationally recognised for their scientific excellence. However, the scale of these facilities and requirement to support their operation and further enhancement presents a number of challenges for the planning of future investment in this capability.

Strategic Impact

Over a long period of time Australia's accelerator-based research has had a significant international impact, influencing for example, a re-direction of the study of nuclear 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 and ion-beam modification and analysis of materials with both fundamental and commercial applications.

Australian researchers have a particularly strong track record of excellence in accelerator-based science, with strong publication records in high-profile international journals, and regular invitations to serve as experts, reviewers and consultants by overseas laboratories and key international organisations such as the International Atomic Energy Agency (IAEA). Australian facilities have been designated as International Research Facilities in Nuclear Physics and by the IAEA as a Regional Resource Unit for the Asia-Pacific region, the latter involving 15 countries as signatories to a Regional Co-operative Agreement.

The availability of local research facilities has been crucial in developing collaborative networks with overseas research groups, building the credentials of Australian researchers and thus securing access to major overseas facilities. These facilities also serve an important postgraduate and postdoctoral training role, 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, and soil erosion; and policy analysis and defence intelligence.

Challenges and Assumptions

Existing accelerator facilities represent an investment of over $70 million and have been built up over several decades through a combination of university funds, competitive grants, commercial income, user fees, and other sources. As such, they represent a significant investment in state-of-the art research infrastructure, the replacement of which would be prohibitively expensive.

A critical issue surrounds the long-term support for the ongoing operation of these facilities, to retain their world-class status and to extend their unique capabilities to service existing and emerging demands. Whilst there is scope to plan and resource some elements of these facilities such as specific beam line end-stations for materials engineering research within the context of other capabilities such as Characterisation and Fabrication, their role as primary experimental platforms for nuclear physics in Australia necessitates further scoping of the national and strategic nature of these facilities in order to develop a plan for future long-term investment. Consideration of these facilities as landmark facilities may be warranted in this context.

From an international perspective and as outlined in the recent Organisation for Economic Co-operation and Development (OECD) Global Science Forum report on Nuclear Physics[16], maintaining large scale facilities and providing free and open access to such facilities is important if Australia is to fulfil its international obligations and continue to access major overseas facilities.

Requirements

Infrastructure

A scoping process should be undertaken to develop a strategic plan for Australia's heavy ion accelerators which can guide future infrastructure investments in this capability. This process would consider user demand and long-term needs of existing national facilities, including the upgrades and enhancements required to support activities in current and emerging research areas, and would also examine the requirements and options for access to both local and overseas facilities.

Support

- Specialised operational and technical support is vital for the ongoing operation of accelerator facilities and to facilitate access to researchers from a variety of disciplines.
- The development and enhancement of technical and research linkages with key overseas facilities in Germany, Japan, France, the USA and Canada requires adequate support.
- Linkages to Characterisation and Fabrication capabilities, and also to developments related to the Sustainable Energy Future capability, should be strengthened.

16 OECD Global Science Forum Working Group on Nuclear Physics, May 2008

Safeguarding Australia

Contextual Framework

Australia's economy, society and infrastructure are areas of vulnerability common across a range of potential threats, including natural and man-made disasters, critical quarantine failure and infectious diseases. Research capabilities are required that deal with prevention, surveillance and response. A number of agencies are developing capability in some of these areas but gaps have been identified especially in fields that relate to planning, threat mitigation and time-responsive decision making.

Central to the capability need are collaboration, integration and coordination. The issues of data management, mining and sharing are highly relevant and tools and techniques that build on the integration of relevant databases and models across organisations and jurisdictions are part of the solution. Online collaborative environments are required to enable researchers from different fields to come together with decision-makers and operational parties.

Components of several of the other capabilities, especially those relating to detection, analysis, surveillance and monitoring are also relevant but need specific consideration from the *Safeguarding Australia* perspective. A case in point is a need to be able to conduct rapid, accurate detection and forensic analysis at a chemical or molecular level, potentially in the presence of hazardous contamination. This capability lies within the scope of biomolecular and characterisation techniques but requires a deliberate focus of the relevant technologies to provide solutions for forensic applications.

Research Capabilities

Through the NCRIS program, investment has been made to establish a better connected national biosecurity system as a top priority. The Australian Biosecurity Intelligence Network (ABIN) has been initiated for this purpose, in addition to the upgrade of containment laboratory capacity through restructure and refurbishment of the Australian Animal Health Laboratory. A further enhancement of ABIN is endorsed in this Roadmap.

A capability, framed in the 2006 Roadmap as Next Generation Solutions To Counter Crime and Terrorism, was not funded and has been reshaped here as Disaster and Hazard Test-Bed to complement the biosecurity focus of ABIN by delivering a capability more broadly applicable to natural and man-made disasters and hazards. An emphasis is placed on but is not confined to:

- Collaborative workspaces and tools where experts from different disciplines (including the social sciences for example) can interact and work together; and
- Enhanced representation and modelling capability, both virtual and physical.

Networked Biosecurity

Description

Biosecurity can be defined as the protection of human health, the economy and the environment from negative impacts associated with diseases and pests. Research in support of biosecurity involves a large range of disciplines (e.g. microbiology, entomology, epidemiology, veterinary pathologists) working in various sectors (human, animal, plant, wildlife and aquatic animal health) and within different agencies and institutions (state, territory and federal agencies, universities, publicly funded research agencies and industry).

Infrastructure to support the diverse needs of biosecurity research includes physical infrastructure (e.g. containment facilities, diagnostic laboratories and reference collections) and "soft" infrastructure to capture and share data such as surveillance datasets. At a national level, an integrated and collaborative approach to biosecurity research, through the establishment of networks and processes that provide access to major existing facilities and expertise, and that links and enables sharing of data and facilitates communication across disciplines, sectors and organisations, is seen as vital to the delivery of biosecurity outcomes.

Within the context of biosecurity, research is part of a continuum that encompasses surveillance, preparedness and emergency response. It is recognised that the infrastructure which supports biosecurity research (e.g. the research networks and laboratories) is an integral part of the operational elements of this continuum and that some biosecurity researchers, especially those in government agencies, are potentially also engaged in considering the broader issues associated with emergency response.

Strategic Impact

Australia is in a particularly vulnerable position for the entry and spread of new infectious diseases and pests. We are geographically placed in a region where emergence and re-emergence of infectious diseases has been occurring regularly. People movement, including but not limited to travel into and out of the mainland by air and sea, is common and rapid. Our large coastline, and in particular the north of the country, presents a critical area for focus. Our ecosystem, plants, animals and human population are at risk from the entry, establishment and spread of many new infectious diseases and pests. Efforts directed at detecting, preventing and/or containing these diseases are of vital importance to Australian, regional and global health.

In order to anticipate, prepare and undertake surveillance and provide input into the strategies for responding to the threats posed by diseases and pests, a multidisciplinary capability that has a strong research component is required. This capability must encompass the coordination and maximum use of the combined physical and human infrastructure that exists in Australian government and research agencies, universities and industry, to enable research that supports the detection, prevention and/or response to disease threats. Furthermore, the establishment of links with regional and global groups through this capability is important to facilitate information and knowledge sharing about new and emerging diseases.

Challenges and Assumptions

Under the NCRIS program, the scoping of the strategic and national infrastructure needs for biosecurity has identified the requirement for a better connected national biosecurity system. Initial investment is being made to establish an Australian Biosecurity Intelligence Network (ABIN) to provide a workspace (both physical and virtual) where data, information and outcomes of research can be shared across organisations, jurisdictions and sectors to support the delivery of improved biosecurity outcomes in Australia.

Whilst considerable progress has been made in developing the ABIN concept and an investment strategy for its implementation, in particular the agreement of jurisdictions towards a nationally collaborative research infrastructure approach, key challenges remain:

- Understanding and acceptance of the biosecurity community that the generic components and functionality of the network will deliver benefits at a local level to researchers. Proposed pilot projects that span scientific disciplines and jurisdictions are seen as critical to demonstrating these benefits and to encouraging cross-sector collaborative behaviours of researchers;
- Continued support and agreement by stakeholders on standards and exemplars for national remote 'grid-enabled' access methods to locally held data, tools and analysis systems;
- Accessing skilled staff who can interpret the discipline-focused ICT needs of researchers and deliver tools to support these needs; and
- Interactions and links with other capabilities including: eResearch Infrastructure; Integrated Biological Discovery; Terrestrial Ecosystems (in particular biological collections); Marine Environments; Characterisation; the geospatial component of Australian Continent.

A view expressed in some quarters is that inadequacies in the existing laboratory infrastructure – such as uneven standards across the country – will limit the capability of ABIN to optimise biosecurity research outcomes and could constrain development in some parts of the country. As responsibility for major investments in laboratories is shared between state, territory and federal governments, coordination between the various agencies within the jurisdictions is vital in order to deliver the required capabilities that best serve the biosecurity system.

Figure K

Requirements

Infrastructure

- » A primary goal is to provide enhanced access to data and to link datasets from different jurisdictions and possibly different security domains. This will include access to data collected in real time as well as extensive, accessible and well-curated collections. Once 'loose coupling' of data has been achieved within the selected ABIN pilot projects, the key to greater usefulness will be extended and more systematic analysis.
- » Real-time modelling and analysis is identified as a need, as well as the use of sophisticated visualisation tools to undertake deep analysis of complex datasets.
- » Collaborative workspaces and tools will enable shared discussion, data and ideas. Videoconferencing will be particularly useful in emergency situations.
- » The underpinning network requirements include connectivity to rural areas, international linkages, and last mile connections for those ABIN participants not connected to the Australian Research and Education Network. In addition, overlay network technologies such as virtual private networks may be needed to manage data security domain issues.
- » The availability of ICT skilled people, who are versed in or have knowledge of the relevant disciplines and can understand the issues, is vital. It is highlighted that ICT expertise on its own is not sufficient; a capacity for translation between the users and the experts must also exist. Related to this is the need to address at a broader level the absence of career paths that result in the current dearth of these resources.

Support

Links to enabling infrastructure (eResearch) services and expertise will be critical, in particular through the Australian National Data Service and the Australian Research Collaboration Service.

Disaster and Hazard Test-bed

Description

A coordinated, collaborative research effort, that spans many organisations and disciplines including physical and social sciences and is supported by appropriate infrastructure, is needed to address the dangers of disasters and hazards. This effort would focus on the effective development and delivery of knowledge and capabilities needed to: evaluate risks; simulate potential outcomes; and plan and prepare for natural and man induced disasters and other hazards. Key aims are to mitigate the impacts, communicate with the public at large to enhance resilience and ensure effective response and recovery. Elements of operational disaster response, recovery and mitigation exist in Australia, but this is a field where it is internationally acknowledged that research and evaluation will make a difference[17].

Some basic infrastructure to enable research in this field currently exists but it is scattered and often siloed within discipline groupings, minimising the effectiveness of the outputs and translation into practice. Other infrastructure is not available in Australia (see Pandemic Case Study on page 77). The focus of the research effort required is a considerable enhancement of a 'test bed' environment to enable simulation both in a physical and virtual sense to enhance our understanding of the likelihood and consequence of hazards and disasters, be they natural or man-made[18], the phenomena they cause and the most effective responses. The research effort requires the integration of sociological data about the responses of humans and how they can be prepared as well as leading edge risk assessment capacity, spatial data analysis and cooperation with experts with a background in disaster and emergency response.

The infrastructure to support this research will encompass simulation tools:

» Models from a very broad range of fields; simulation facilities and integrated test beds for assessing physical vulnerabilities;

» Software tools including spatial data analysis; networks and facilities that will enable connectivity;

» Data sharing and expertise linking across a wide range of disciplines; and

» Decision-support tools.

A collaborative approach is needed to avoid duplication of effort and to enable risks to be compared for different hazards and for different locations and to learn the lessons from actual events. It also necessitates learning to occur from actual events through forensics[19].

The expected outcome is a heightened national capacity and a sound knowledge base for informed decision making to reduce the impact of disaster based on a consistent and coordinated system of data collection, research, analysis and continuous improvement.

Strategic Impact

Disasters have an enormous economic cost and inflict a massive social cost on the community. They may strike anywhere, anytime and no state or territory in Australia is immune. Features common to disasters, regardless of origin, are widespread destruction and potential for escalation particularly in areas of high population density. Recent examples of catastrophic events in the world illustrate an enormity of scale far beyond the resources of single nations. Disaster management and mitigation are therefore a vital long-term investment in the welfare of the community and environment that requires significant foresight and planning.

The breadth of vulnerabilities to be considered is a substantial challenge. It requires a national collaborative effort across research disciplines and across all three levels of government, in close partnership with industry and with community involvement and support. Considerable effort is being made by key organisations with relevant skill sets and areas of expertise but knowledge gaps exist. An emerging area of strategic relevance to critical infrastructures (and their interdependencies) is cybersecurity. Without a functioning cyberspace, national critical systems such as financial, water, power, as well as a growing number of emergency services, can no longer operate effectively. Imperatives for securing data relate not only to researchers' need to maintain integrity of their research but are also specific to a number of priority research areas, including health, cultural and biosecurity.

Many government agencies and private sector companies including owners and operators of critical infrastructure in Australia are currently unable to access the full range of risk analysis tools and test bed environments, including vulnerability modelling facilities, that they require. The cost to establish such research facilities is beyond the scope of most enterprises and individual jurisdictions. Without such facilities and a strong collaboration between government, industry and research providers, large portions of Australia's critical infrastructure and its population are at risk of emerging security threats and natural disasters.

17 Both the UK and US are investing in facilities relevant to simulating disasters within their environmental contexts.

18 Examples are flood, severe storm, bushfire, tropical cyclone, landslide, earthquake and tsunami events; catastrophic systems failure, major pollution events, acts of terrorism or war.

19 Forensics encompasses the ability to detect, accurately and rapidly in the field, chemical, biological, radiological, nuclear and explosive (CBRNE) agents. Pre-event forensics, the ability to trace the origin and history of materials intercepted before a terrorist act takes place for example, can also have a significant deterrent effect. Computer (digital) forensics is another emerging specialisation.

Challenges and Assumptions

Australia lacks an environment that can leverage the wealth of knowledge developed across all sectors - including the university sector - for managing disasters. Accurately modelling and testing the likelihood and potential impacts of disasters provides the tools for more informed decision-making but many different aspects require consideration. To give an example: in disaster management, a model can be a cognitive one, representing how people perceive and act; a social one representing social structures and interaction; a physical one representing how a tornado develops; an optimisation one to allocate and route resources (such as ambulance) to locations; or a simulation one mimicking a scenario to train emergency management operators.

The challenge in establishing a collaborative test-bed environment and to be able to integrate findings is to provide the glue[20] that enables the models to fit together and for different modelers (social, cognitive, mathematical, ICT, etc.) and user groups to be willing to collaborate and draw on physical and virtual simulations to enhance the predictive tools. An environment is needed for development of the appropriate infrastructure and the intellectual capacity in synthesis and to facilitate conversation and learning amongst diverse research areas. The solution requires "big picture" thinking and long-term commitment but the gains will be immense - better utility of knowledge, data and expertise applied to the problems at hand.

Surveillance, monitoring, pre- and post-event forensics are other important pieces of the jigsaw. Multi-disciplinary model simulations have a strong dependence on technologies and expertise encompassed under each of the other capabilities such as DNA technology, detection and analysis of CBRNE agents, and remote sensing. The challenge here is support for the particular requirements of *Safeguarding Australia*.

Requirements

Infrastructure

There are parallels with the Terrestrial Ecosystems Research Network being developed under the NCRIS program, in that there is a need to draw together into an overall capability many existing activities such as threat anticipation in the Defence Science and Technology Organisation and predictive modelling for critical infrastructure protection in Geoscience Australia. This infrastructure would establish the hardware, software and middleware backbone to facilitate a collaborative modelling environment. Some of the requirements include advanced modelling software and high performance computer facilities for hazard simulation, risk assessment and network interdependency analyses customised for the Australian context.

While there needs to be an emphasis on connectedness and building upon existing capability, a unique physical facility may be required for evaluating innovative technology, practices and procedures, and help to build resilient infrastructure. For example, it could comprise an integrated test bed for research and development of protective technologies and testing the built environment in extreme events.

Support

The infrastructure will be under-exploited without a simultaneous build in people. This would include enhancing cross disciplinary expertise; expanding capacity in the 'translation' between research and operational organisations; and building a network of multi-disciplinary researchers.

The facility requires access to and integration of social and infrastructural databases and the transfer of models between researchers. This includes access to post disaster and post hazard studies to provide valuable insights.

Support of technical and network staffing will enable gathering and processing of data, research outputs and ensure the fine level of detail that is required to reduce risk at the local level.

Support for scenario modelling requires software, data collection and personnel.

20 The glue of models in IT consists of an architecture, standards and protocols.

Case Study

Pandemic Preparedness

Decision makers at federal government level, within the Australian Health Protection Committee and in state and territory jurisdictions need to be appropriately armed with reliable, readily available, consistent and timely information to enable them to make good decisions in the event of a threat such as a pandemic.

Based on recent experience, the Department of Health and Ageing (DoHA) has recognised modelling capacity and capability as a critical enabler of effective pandemic and health emergency planning.

At present our ability to deliver this capability is quite limited. DoHA has put in place some of this capability for pandemic planning and from this process it is clear there is a limited resource in Australia and there is very little 'shared space' at present. Government departments, academia and private enterprise are currently 'dabbling' in this space. A test bed environment that identifies, supports and uses the capability is required to add to the robustness of the Australian communities' capacity to predict and respond to potential pandemics such as influenza.

The broad requirements of such a capability include:

» Information that is accessible and reliable (within an agreed confidence level);

» Data that is readable to a wide audience and timely;

» Responsiveness and adaptiveness to changes in assumptions/ circumstances; and

» Models that have been tested against real data and for sensitivity to margins of error in assumptions, and which are continually enhanced by research, evaluation and simulation.

The main requirements of a modelling capability for a pandemic are:

» To ensure stockpile deployment assumptions are reasonable;

» An ability to take account of social interactions and spatial influences;

» Accuracy in predicting the spread of disease;

» To predict the impact of the pandemic in various areas such as social and health systems, infrastructure and economic;

» To predict capacity to respond at national, state and territory and local level; and

» To inform critical decision points for interventions and subsequent removal of interventions.

Important factors in disaster management are the issues of interdependency, interaction and the cascading effect. Coupling the modelling with ongoing simulations such as 'Exercise Cumpston'[21] through the test bed environment would significantly enhance the outcomes.

If Australia could confidently model all of the above sub-systems for a pandemic then the 'what if' questions legitimately considered by decision makers at all levels will be powerful enablers of good decision making practice.

21 Exercise Cumpston 2006 tested Australia's preparedness for responding to pandemic influenza, including the integration of the many response elements required.

Appendix A Details of the review of the 2006 NCRIS Roadmap

The review of the 2006 Roadmap took place in the first half of 2008. There were three key stages of this review in the following order:

1. Release of a Discussion Paper for consultation;
2. Release of an Exposure Draft of the Strategic Roadmap for Australian Research Infrastructure for consultation;
3. Release of the final Strategic Roadmap for Australian Research Infrastructure.

To assist the NCRIS Committee in undertaking the review, five Expert Working Groups were formed around the National Research Priorities – Environmentally Sustainable Australia, Frontier Technologies for Building and Transforming Australian Industries, Safeguarding Australia, Promoting and Maintaining Good Health – and the Humanities, Arts and the Social Sciences.

The formation of the Expert Working Groups around the National Research Priorities reflected the process taken to create the 2006 Roadmap, and provided a useful basis for identifying infrastructure requirements around priority research areas.

A sixth group, the Information and Communication Technologies (ICT) Strategy Group, was convened to consider the underpinning ICT requirements and issues broadly. Five representatives from this Group were assigned to each assist an Expert Working Group in reviewing, capturing and articulating the requirements for that Group's area of consideration.

Members of the Groups were drawn from a wide range of discipline areas and institutions. They were selected on the basis of their skills and knowledge in specific areas, and their ability to engage with and seek the views of their peers and other stakeholders.

A list of members of each of the Expert Working Groups and ICT Strategy Group is below.

Promoting and Maintaining Good Health working group

Professor Caroline McMillen (University of South Australia) – Chair

Professor Doug Hilton (Walter and Eliza Hall Institute)

Professor Ian Smith (Monash University)

Professor Louisa Jorm (University of Western Sydney)

Professor James Best (University of Melbourne)

Dr Richard Head (CSIRO)

Professor Simon Foote (Menzies Research Institute)

Professor Brandon Wainwright (University of Queensland)

Professor Rob Sanson-Fisher (University of Newcastle)

Professor John Miners (Flinders University)

Mr Neil Thelander (Queensland University of Technology) – ICT Strategy Group representative

Humanities, Arts and the Social Sciences working group

Professor Graeme Turner (University of Queensland) – Chair

Professor Susan Rowley (University of Technology Sydney)

Dr Deborah Mitchell (Australian National University)

Professor Linda Rosenman (Victoria University)

A/Professor Susan Broomhall (University of Western Australia)

Professor Stuart Cunningham (Queensland University of Technology)

Professor Margaret Harris (University of Sydney)

Professor Linda Connor (University of Newcastle)

Professor Paul Turnbull (Griffith University)

Professor Graeme Hugo (University of Adelaide)

Professor Paul Bonnington (Monash University) – ICT Strategy Group representative

Frontier Technologies working group

Professor Rod Hill (Monash University) – Chair

Dr Cathy Foley (CSIRO)

Professor Robert Elliman (Australian National University)

Professor Matthew Colless (Anglo Australian Observatory)

Professor Andrew Dzurak (University of New South Wales)

Professor Leon Sterling (University of Melbourne)

Professor Colin Raston (University of Western Australia)

A/Professor Nico Voelcker (Flinders University)

Professor Mark Baker (Macquarie University)

A/Professor Joe Shapter (Flinders University)

Dr Ben Evans (Australian National University) – ICT Strategy Group representative

Environmentally Sustainable Australia working group

Dr Chris Pigram (Geoscience Australia) – Chair

Professor Alistar Robertson (University of Western Australia)

Professor Stuart Bunn (Griffith University)

Dr Ian Poiner (Australian Institute of Marine Science)

Professor Ruth Fincher (University of Melbourne)

Dr Neil McKenzie (CSIRO)

Professor John Dodson (Australian Nuclear Science and Technology Organisation)

Dr Rob Lewis (South Australian Research and Development Institute)

Dr Ian Atkinson (James Cook University) – ICT Strategy Group representative

Safeguarding Australia working group

Professor Helen Garnett (Charles Darwin University) – Chair

Dr Greg Simpson (CSIRO)

Mr Neil Bryans (Defence Science and Technology Organisation)

Dr James Robertson (Australian Federal Police)

Dr Martin Barlass (Department of Primary Industries, Victoria)

Professor Hussein Abbass (Australian Defence Force Academy)

Associate Professor Priyan Mendis (University of Melbourne)

Professor Sam Makinda (Murdoch University)

Professor David King (James Cook University)

Ms Raelene Thompson (Department of Health and Ageing)

Mr Paul Sherlock (University of South Australia) – ICT Strategy Group representative

ICT Strategy Group

Dr Rhys Francis (Australian eResearch Infrastructure Council) – Chair

A/Professor Ian Atkinson (James Cook University)

Professor Paul Bonnington (Monash University)

Professor James Dalziel (Macquarie University)

Mr Paul Davis (Victorian eResearch Strategic Initiative)

Dr Ben Evans (Australian National University)

Professor Brian Fitzgerald (Queensland University of Technology)

Professor Jane Hunter (University of Queensland)

Mr George McLaughlin (Asia Pacific Advanced Networks)

Mr Don Robertson (AARNet Pty Ltd)

Mr Paul Sherlock (University of South Australia)

Mr Neil Thelander (Queensland University of Technology)

Professor Tony Williams (Australian Research Collaboration Service)

Professor Darrell Williamson (CSIRO ICT Centre)

Appendix B Challenges, enablers and considerations

The review of the 2006 Roadmap placed a particular focus on determining the challenges, enablers and other considerations that surround successful implementation of a collaborative approach to research infrastructure. In particular, specific challenges and assumptions underpinning each capability were identified, and indicated where attention needs to be placed in evolving and implementing these capabilities. Continued funding and sustainability of the approach taken to date were common areas of concern highlighted by stakeholders. Points arising during the review of the 2006 Roadmap included:

- There is support for the view that committed ongoing support for national research infrastructure would enable planning for the refreshment and replacement of infrastructure to take place in a structured fashion. Within this, full lifecycle costs within institutions and nationally are key considerations. In addition, prioritising the areas that have the potential to be funded within a capability requires careful consideration and consultation with the stakeholders involved.
- In a collaborative approach to research infrastructure at the scale of a program such as NCRIS, challenges in bringing people and groups together are expected. In many areas, the implementation of the NCRIS program has drawn together otherwise discrete or distinct communities. Even within communities that have a common base, diversity exists, for example differences in approach between states or between governments and universities. Bringing together these fragmented arrangements represents a significant challenge.
- The challenges of collaboration can increase with the size of the community (such as with the many communities in the HASS research sector or the environment sector) or the depth of engagement needed to reach successful collaboration (such as the resources needed to draw out the ICT needs of capabilities). Disagreement or lack of common understanding while developing capabilities (e.g. during facilitation) are specific issues for collaboration that need to be addressed.
- It is important that all stakeholders have an accurate perception of the purpose of a research infrastructure funding program such as NCRIS; the level and type of research infrastructure it funds; and of which parties are responsible for what elements (for example, for funding ICT). Acceptance or understanding that 'national' collaborative infrastructure can have relevance for researchers at a local level is important.
- The consideration of cross-capability linkages while developing and implementing a capability can have significant advantage for that capability. These linkages can be characterised by the need for common infrastructure (such as remote sensing or ICT) or the need to link the research itself (for example characterisation with fabrication).
- The resolution of specific issues may significantly affect how a capability is implemented. These include, for instance issues around privacy and data sharing.
- A leadership role for a number of organisations, including the lead funding agency and key stakeholders is considered vital.
- The extreme readiness of some research communities to participate in collaborative infrastructure delivery – for example, Astronomy – lends a different focus to these communities' issues. For these groups, collaborative behaviours are usually established and a prime focus may be on issues of commitment of support and sustainability of funding.

Appendix C Funded Capabilities from the 2006 NCRIS Roadmap

NCRIS Capability Area	Facilities	NCRIS Funding
Evolving Biomolecular Platforms and Informatics	BioPlatforms Australia	$50 million
	European Molecular Biology Laboratory (EMBL)	$3 million
Integrated Biological Systems	Australian Phenomics Network	$16 million
	Australian Plant Phenomics Facility	$15.2 million
	The Atlas of Living Australia	$8.2 million
Characterisation	National Deuteration Facility	$3.5 million
	Australian Synchrotron - beamlines	$13.9 million
	Australian Synchrotron Research Program – access to international facilities	$3.6 million
	Australian Microscopy and Microanalysis Facility	$19.1 million
	National Imaging Facility	$7.2 million
Fabrication	Australian National Fabrication Facility	$41 million
Biotechnology Products	Manufacture of Human Cells	$7.6 million
	Recombinant Proteins and Biofuels	$21.4 million
Networked Biosecurity Framework	Australian Animal Health Laboratory	$8.5 million
	Australian Biosecurity Intelligence Network	$16.5 million
Radio and Optical Astronomy	Astronomy Australia Limited	$45 million
Integrated Marine Observing System	Integrated Marine Observing System	$50 million
	Repair and Maintenance of Southern Surveyor	$5.2 million
Structure and Evolution of the Australian Continent (Geoscience and geospatial)	AuScope	$42.8 million
Platforms for Collaboration (e-Research infrastructure)	National Computational Infrastructure	$26 million
	Australian Research Collaboration Service	$20.5 million
	Australian National Data Service	$21 million
	Australian Access Federation, Networks, AeRIC and other investments	$14.5 million
Population Health Research Network	Funding agreement under development	$20 million
Terrestrial Ecosystem Research Network	Investment plan currently under development	$20 million