

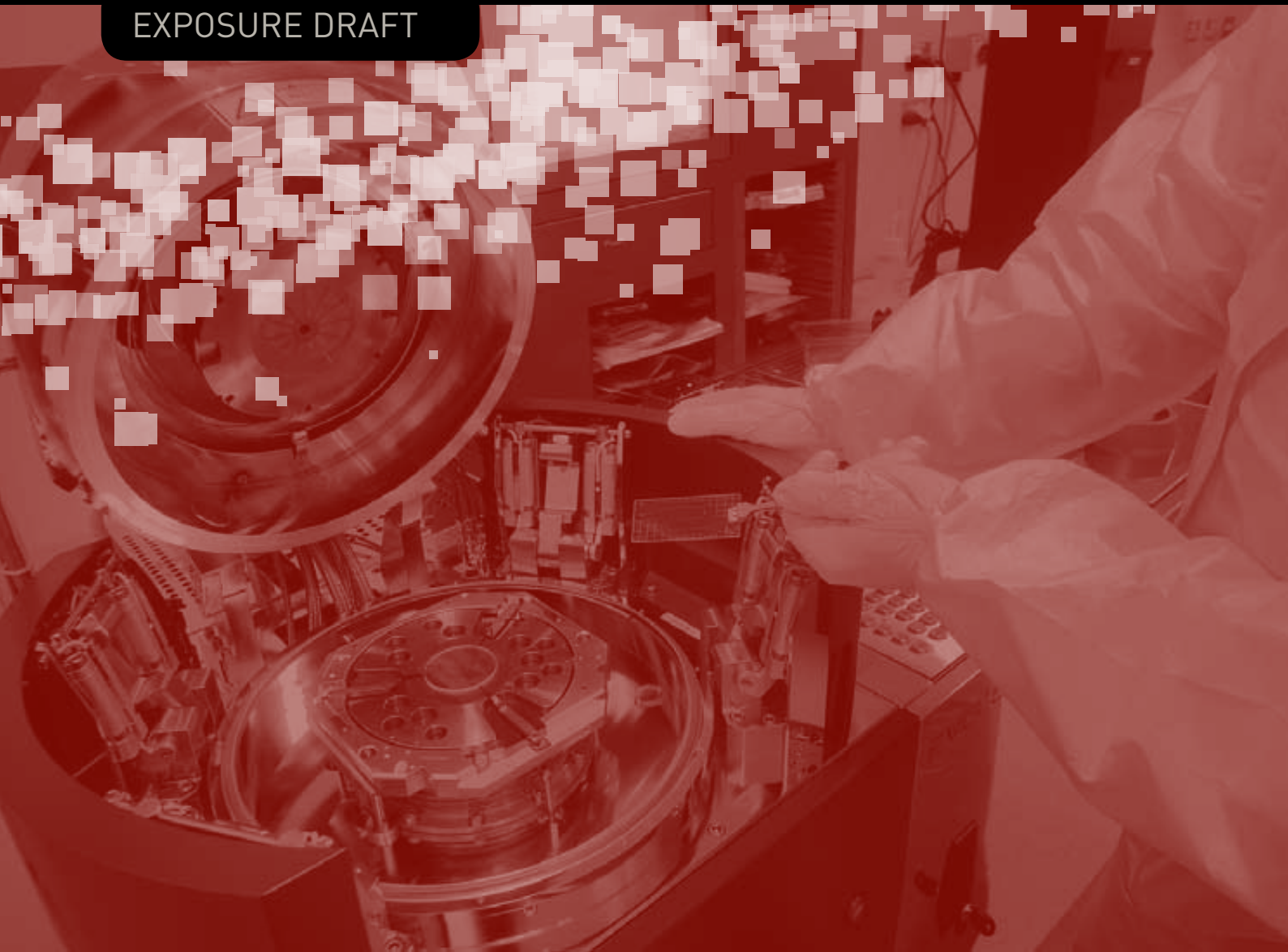


**Australian Government**

**Department of Innovation  
Industry, Science and Research**

# **2011 STRATEGIC ROADMAP FOR AUSTRALIAN RESEARCH INFRASTRUCTURE**

**EXPOSURE DRAFT**





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# Consultation

This Exposure Draft, released June 2011, is the result of work being undertaken to develop a 2011 Strategic Roadmap for Australian Research Infrastructure (2011 Roadmap).

There are three key stages of the 2011 Roadmap development process:

1. Release of a Discussion Paper for consultation (March 2011)
2. Release of an Exposure Draft (this document) for consultation
3. Release of the 2011 Strategic Roadmap for Australian Research Infrastructure (expected in September 2011).

Your feedback is sought on this Exposure Draft. You may choose to comment on the entire Exposure Draft or on particular sections or capabilities. However, please note that the National Research Infrastructure Council's *Strategic Framework for Research Infrastructure Investment* (pages 12 to 15) has been developed through an earlier consultation process.

Your feedback can be formal (for example, an official institutional submission) or informal (for example, a brief email).

Responses to this Exposure Draft will be used to help refine the final version of the 2011 Roadmap and will be made public on the Department of Innovation, Industry, Science and Research website. **Please indicate when you send your response if you do not want it to be made public.**

Responses to the Exposure Draft should be sent to the Department of Innovation, Industry, Science and Research electronically (preferred) by **COB Friday, 22 July 2011.**

If you have any questions, these should be directed to the Roadmap team at the contact details below.

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# Introduction

## Importance of Innovation and Research

The Australian Government is committed to a richer, fairer and greener Australia, built on a broad-based and sustainable national economy.

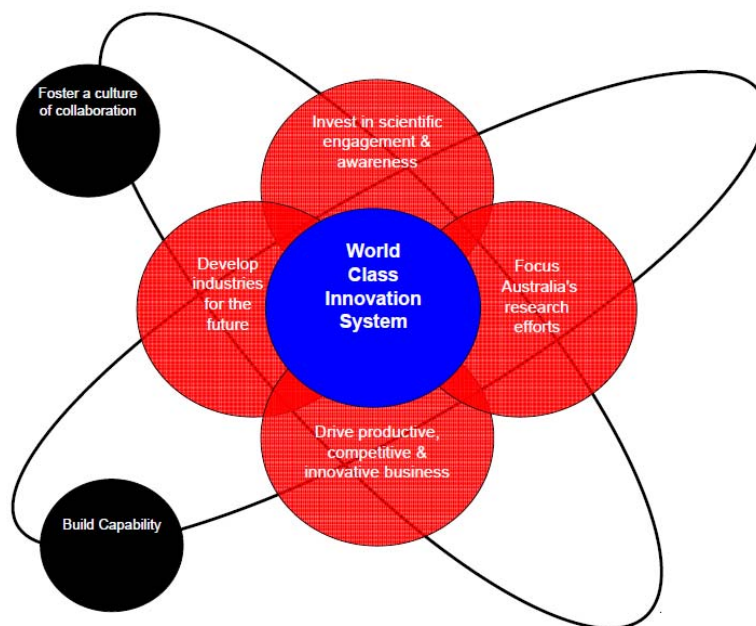
The government has outlined the need to support Australian entrepreneurs and innovators in its ten year innovation agenda *Powering Ideas: An Innovation Agenda for the 21st Century*<sup>1</sup>. This agenda focuses on making Australia more prosperous and competitive, and positions us to respond to the big challenges of our generation, including climate change, social disadvantage and healthcare.

*Our capacity for invention and discovery depends on the strength of our national innovation system. This is the system we use to harness the creativity of our people, to transform great ideas into great results for the community, the economy and the environment. Genius is wasted if you can't capture it and apply it to the real world. That's what the national innovation system does.*

*Entrepreneurs, policy-makers, researchers, workers, and consumers are all part of the innovation system. One way to make the system stronger is by strengthening its constituent parts. The other is by strengthening the links between those parts. Australia needs to do both.*<sup>2</sup>

Innovation is critical to economic growth. For example, as noted by the Organisation for Economic Co-operation and Development (OECD), 'developing the innovative effort, including formal research and development, is the sine qua non of growth'<sup>3</sup>. The OECD also notes that while a stable macroeconomic environment provides the overall basis for growth, key factors such as government policy to foster innovation and enhancing human capital are needed for growth to occur.

Figure 1 – Innovation agenda diagram



<sup>1</sup> <http://www.innovation.gov.au/Innovation/Policy/Pages/PoweringIdeas.aspx>

<sup>2</sup> <http://www.innovation.gov.au/Innovation/Policy/Documents/PoweringIdeasExecutiveSummary.pdf> , pg 1

<sup>3</sup> <http://www.oecd.org/dataoecd/2/31/39374789.pdf>

It is widely accepted both in Australia and internationally that public investment in research plays a significant role in building innovation capacity and driving productivity<sup>4, 5, 6</sup>. For example, the OECD has identified that public and private research and development exert significant effects on productivity in Australia<sup>7</sup>.

A robust and thriving research sector underpins a world-class innovation system. The knowledge resulting from excellent research leads to new discoveries, solutions to problems and enables new applications and technologies, which will drive the development of industries for the future.

There is also a clear and increasing imperative to ensure a coordinated, coherent approach to maximising the innovation dividend.

As the Australian Academy of Science observed in its submission to the Roadmap Discussion Paper,

*If we support our best research, and train our young people so they can take up the skilled jobs that will be generated, Australia will be able to emerge from the present period as a knowledge-based, economically competitive and intellectually vibrant country.*<sup>8</sup>

For research to flourish in Australia, a number of factors need to be present. A vital component of a high-performing research sector is the availability of quality research infrastructure. Australian researchers, if they are to participate in addressing the big, complex research problems facing Australia and the world, need to be equipped with the right research tools.

*Research undertaken in Australia's industry, public, not for profit and university sectors is inextricably linked to Australia's overall innovation performance. In order to best meet the needs of the nation, investments in research infrastructure should be prioritised based on areas in which Australia seeks to develop leading research capability and be balanced by a focus on innovation outcomes and the contribution that research makes to national productivity and prosperity.*<sup>9</sup>

In addition, Australia needs to ensure a high level of engagement with the international science and research community. Global connectivity is vital if we are to address the challenges facing the world today.

## Research Infrastructure

World-class research infrastructure boosts the productivity of Australia's researchers. With finite resources, Australia needs to target its investments in research infrastructure, considering its priorities in both a national and an international context.

Infrastructure to support research is an enabler which has a range of positive outcomes including, development of skills and knowledge and the promotion of collaboration, which in turn generates benefits that exceed the sum of the individual research parts and enables faster resolution of intractable problems.

Australian researchers need to have access to leading-edge infrastructure in order for their research outputs to be internationally competitive. This will additionally attract international researchers to Australia to undertake their work.

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<sup>4</sup> Productivity Commission, 2007, <http://www.pc.gov.au/projects/study/science/docs/finalreport>

<sup>5</sup> National Academy of Sciences, 2010, <http://www.aps.org/policy/reports/upload/rags-revisited.PDF>

<sup>6</sup> Martin and Tang, 2007, [www.erawatch-network.eu/reports/sewp161.pdf](http://www.erawatch-network.eu/reports/sewp161.pdf)

<sup>7</sup> <http://www.oecd.org/dataoecd/2/31/39374789.pdf>

<sup>8</sup> Australian Academy of Science submission in response to the 2011 Roadmap Discussion Paper

<sup>9</sup> Australian Industry Group submission in response to the Strategic Framework for Research Infrastructure Investment Discussion Paper

Research infrastructure is defined by the National Research Infrastructure Council (NRIC)<sup>10</sup> as comprising the assets, facilities and services which support research across the innovation system and which maintain the capacity of researchers to undertake excellent research and deliver innovation outcomes.

The *2011 Strategic Roadmap for Australian Research Infrastructure* has been developed in consultation with the research sector to identify strategic priorities for Australia over the next five to ten years. It builds on the *2006 National Collaborative Infrastructure Research Strategy (NCRIS) Strategic Roadmap*<sup>11</sup> and the *2008 Strategic Roadmap for Australian Research Infrastructure*<sup>12</sup>.

## **Directions in Research Infrastructure**

The strategic direction that Australia has taken in national, collaborative infrastructure planning and investment in recent years has resulted in important infrastructure capability as well as establishing mechanisms for collaborative decision-making and priority setting.

As research infrastructure funded under NCRIS<sup>13</sup> and the Super Science Initiative<sup>14</sup> has matured, it has begun to deliver on the promise of strategic, national, collaborative investment. The NCRIS approach has been successful in achieving the creation of improved national research capability through the development of new facilities and leveraging existing capacity. This increased capacity is supporting novel, collaborative research activities that are already, or have the potential to be, world-class.

Of critical importance at this stage in the development of the national, collaborative research infrastructure system are:

- the need to sustain the investments made to date, to ensure a predictable, stable and continuous set of infrastructure services on which researchers and other infrastructure providers can rely
- the need to further connect and integrate the infrastructure that has been funded to date, to overcome some of the silos that have built up as a result of focused implementation
- the need to provide professional infrastructure services, moving beyond allowing access across institutional firewalls and into the realm of actively seeking to provide services to meritorious researchers regardless of institutional or research group affiliation
- a continued, deeper focus on data integration and interoperability – supported by infrastructure both within and between existing capabilities – to enable research to tackle complex, multi-disciplinary problems
- the need to ensure research infrastructure integrates generic and specific services in a way that is seamless to the researcher.

Increasingly, strategic long-term planning exercises (Roadmaps) are playing an important role in the prioritisation of research infrastructure internationally. Roadmapping is of particular value since it allows investment to be considered in a broad context that includes national and global priorities. A prime example is the European Strategy Forum on Research Infrastructures (ESFRI) 2010 Roadmap<sup>15</sup>.

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<sup>10</sup> [www.innovation.gov.au/Science/ResearchInfrastructure/Pages/NRIC.aspx](http://www.innovation.gov.au/Science/ResearchInfrastructure/Pages/NRIC.aspx)

<sup>11</sup> [http://ncris.innovation.gov.au/Documents/2006\\_Roadmap.pdf](http://ncris.innovation.gov.au/Documents/2006_Roadmap.pdf)

<sup>12</sup> [http://ncris.innovation.gov.au/Documents/2008\\_Roadmap.pdf](http://ncris.innovation.gov.au/Documents/2008_Roadmap.pdf)

<sup>13</sup> [www.innovation.gov.au/Science/ResearchInfrastructure/Pages/NCRIS.aspx](http://www.innovation.gov.au/Science/ResearchInfrastructure/Pages/NCRIS.aspx)

<sup>14</sup> [www.innovation.gov.au/Science/ResearchInfrastructure/Pages/SuperScience.aspx](http://www.innovation.gov.au/Science/ResearchInfrastructure/Pages/SuperScience.aspx)

<sup>15</sup> [http://ec.europa.eu/research/infrastructures/index\\_en.cfm?pg=esfri](http://ec.europa.eu/research/infrastructures/index_en.cfm?pg=esfri)

## ***A National Approach***

In order to develop a world class, integrated suite of research infrastructure, a national, collaborative approach needs to be taken. This approach must consider the responsibilities and investments across a range of jurisdictions and the publicly funded research sector.

A number of federal, state and territory portfolios, for example, health, energy, education, heritage, arts, environment and agriculture, fund and host research infrastructure. In addition, a wide range of facilities funded as a result of previous Roadmaps, such as high-performance computing infrastructure to support climate research, are relied upon by other agencies. The increasingly interdisciplinary nature of research and recognition of the potential to re-use data across multiple fields raise new inter-jurisdictional challenges to implementing capabilities in this Roadmap.

This Roadmap includes reference to activities that are being implemented by departments other than the Department of Innovation, Industry, Science and Research (DIISR). The inclusion of other portfolios' initiatives in the Roadmap is intended to recognise the breadth of activity in the area and to put research infrastructure capability in its broader context.

Whilst a national approach is vital, this must be considered in the context of international developments. Australian investment in research infrastructure should not be limited to Australian based facilities. In some instances, it is more appropriate and cost-effective for Australia to contribute to multinational facilities to gain the best benefit for Australian science.

## ***Investment principles***

In parallel with the development of the 2011 Roadmap, NRIC has developed a *Strategic Framework for Research Infrastructure Investment* in consultation with research sector stakeholders<sup>16</sup>. The Strategic Framework can be found on pages 12 to 15. The principles set out in the Strategic Framework are fundamental to the success of research infrastructure investment and will provide direction and context for the design of any future programs to implement the 2011 Roadmap.

The Strategic Framework recognises that in order to maximise the benefits from research infrastructure investment, funding must be available to support not only capital costs. Other key elements that require support include governance, skilled technical support staff, operations and maintenance. The research sector has repeatedly emphasised that human capital is required to deliver efficient and viable research infrastructure facilities.

A related challenge is the availability of skilled staff to provide technical support to the research community, along with the development of career paths. This challenge will need to be considered in conjunction with the recently announced Research Workforce Strategy, *Research Skills for an Innovative Future*<sup>17</sup>.

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<sup>16</sup> <http://www.innovation.gov.au/Science/ResearchInfrastructure/Pages/NRIC.aspx>

<sup>17</sup> <http://www.innovation.gov.au/Research/ResearchWorkforceIssues/Documents/ResearchSkillsforanInnovativeFuture.pdf>

## Development of the 2011 Roadmap

The *2004 Final Report of the National Research Infrastructure Taskforce*<sup>18</sup> identified the need for a collaborative, rather than competitive, approach to planning medium to large research infrastructure investments.

The first Strategic Roadmap, developed in 2006, identified the priority capabilities for the NCRIS investments. The 2008 Roadmap formed the basis for the Australian Government's 2009 Super Science Initiative funded from the Education Investment Fund (EIF)<sup>19</sup>.

The 2011 Roadmap has been developed by DIISR, with strategic oversight from NRIC. An outline of the process is at Appendix A, including details of the membership of the Expert Working Groups (EWGs).

In the development of the 2011 Roadmap, the research community was asked to consider future research trends, the strategic importance of those trends to Australia and the infrastructure services required to enable Australia to capitalise on those trends. This meant looking beyond the current needs of today's research, to the sets of research infrastructure services that a broad range of researchers would use in the future, perhaps in ways that are only emerging today.

The inter-relatedness and complexity of global challenges increasingly demands a systems approach to research and the development of research capability, including infrastructure, human capability and collaboration networks (nationally and internationally).

Feedback to the Roadmap process has confirmed a shift in research towards systems thinking, and for research infrastructure to recognise the convergence of various discipline areas. This systems approach is supported by underpinning eResearch infrastructure which must be closely linked with discipline-specific activities.

The 2011 Roadmap has identified a number of research infrastructure requirements that could build upon existing projects, along with new and emerging priorities. There has been significant investment in the capabilities identified in the 2006 and 2008 Roadmaps and this needs to be taken into account in implementing the 2011 Roadmap.

This Roadmap is primarily concerned with national research infrastructure at a medium to large-scale, identifying capabilities likely to have a strategic impact on research in Australia. The development of additional capacity in existing landmark facilities has also been considered and identified in the 2011 Roadmap.

NRIC has proposed a 'Process to identify and prioritise Australian Government Landmark research infrastructure investments'<sup>20</sup> which is currently under consideration by the government as part of broader deliberations relating to research infrastructure. NRIC proposed that research infrastructure involving a minimum of \$100 million in funding from the Australian Government (for capital and other associated costs) over the first five years of operation be considered separately, as Landmark research infrastructure.

### ***Facilitation process***

To ensure a strategic focus within the Roadmap, the capability areas identified have been described at a high level. Once decisions have been made regarding future funding for national, collaborative research infrastructure, it is expected that a facilitation process similar to that undertaken to implement the NCRIS capabilities would define the next level of detail. This would include a structured consultation with relevant stakeholders at the capability level to articulate the specific

<sup>18</sup> [http://ncris.innovation.gov.au/Documents/NRIT\\_Report.pdf](http://ncris.innovation.gov.au/Documents/NRIT_Report.pdf)

<sup>19</sup> <http://www.deewr.gov.au/HigherEducation/Programs/EIF/Pages/default.aspx>

<sup>20</sup> <http://www.innovation.gov.au/Science/Documents/LandmarkDiscussionPaper.pdf>

investments, co-investment, recommendations as to location and operating entity, and the operating model for each capability. Ideally, it should also involve consideration of how the research infrastructure facilities can be a platform for greater engagement between the research sector and industry.

During the development of this Roadmap, detail on many specific investments outlined in the submissions, consultations and advice from the EWGs has been collected. This material will form an important starting point for any future facilitation process.

An important aspect of facilitation, identified in the *2010 NCRIS Evaluation Report*<sup>21</sup>, is the capacity of facilitators to engage the research community to work together to bring forward investment proposals, which optimise resource allocation. The collaborative focus of facilitation provides a means of bringing together previously isolated members of the research community.

In the case of capability areas identified in the Roadmap but not previously funded, there may be a need to undertake a scoping study to further define the requirements and to understand the ways in which they could be implemented, including in the context of other portfolio and government research and research infrastructure investments.

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<sup>21</sup> <http://ncris.innovation.gov.au/eval/Pages/default.aspx>

# STRATEGIC FRAMEWORK FOR RESEARCH INFRASTRUCTURE INVESTMENT

*Powering Ideas*, the Australian Government's innovation agenda, aims to build a stronger national innovation system to assist in creating a better Australia – one that can meet the challenges and grasp the opportunities of the twenty-first century.

*Powering Ideas* included the creation of the [National Research Infrastructure Council](#) (NRIC) to provide strategic advice on future research infrastructure investments.

The *Strategic Framework for Research Infrastructure Investment* has been developed by NRIC in consultation with the research sector to guide the development of policy advice and the design of programs related to the funding of research infrastructure. The Council will undertake stewardship, promotion and championing of the Framework across the Australian Government and the States and Territories.

Investment in innovation and research drives productivity. Excellent research infrastructure, addressing national priority areas, is necessary to deliver high-quality research and innovation outcomes, to enable Australia to be globally competitive. The principles identified in this Strategic Framework will ensure that the approaches used to plan, fund and develop research infrastructure deliver the maximum contribution to economic development, social wellbeing, environmental sustainability and national prosperity.

## Purpose of the Strategic Framework

The purpose of the Strategic Framework is to:

- identify principles to guide the development of policy advice and design of future programs related to the funding of research infrastructure;
- ensure that research infrastructure delivers the maximum outcome for the nation for the money invested; and
- improve consistency and coordination of Australian Government and State and Territory programs that support research infrastructure.

The applicability of the Strategic Framework principles will vary depending on the scale of the research infrastructure investment.

For the purpose of this Framework, investment in research infrastructure has been divided into three broad categories:

- Local – research infrastructure which could be expected to be owned and operated within a single institution.
- National – research infrastructure on a scale generally not appropriate to be owned or operated by a single institution and which often supports collaborative research and is generally regarded as part of the national research capability.
- Landmark – large-scale facilities (which may be single-site or distributed) that serve large and diverse user communities, are generally regarded as part of the global research capability, and engage national and international collaborators in investment and access protocols.

## Definition of Research Infrastructure

Research infrastructure comprises the assets, facilities and services which support research across the innovation system and which maintain the capacity of researchers to undertake excellent research and deliver innovation outcomes.

## Principles for Research Infrastructure Investment

### Continuity of Funding

- Research infrastructure funding programs should be ongoing and predictable, to achieve optimal use of funds.
- Infrastructure that continues to be a priority should be able to access funding for ongoing operations.

#### Guiding considerations

- *Ongoing and predictable funding programs support a more strategic, collaborative and planned approach to research infrastructure investment.*
- *Ongoing operational funding for priority national and landmark research infrastructure assists in maximising the benefit from the original investment.*

### Holistic Funding

- Funding required to support research infrastructure will vary between elements, including capital costs, governance, skilled technical support staff and operations and maintenance. Support should be available to cover these key elements.
- Funding programs should allow some funding for project development costs, either for a facilitation-based process or for project development and scoping activities.
- In the context where not all national and landmark infrastructure would necessarily be replaced, depreciation for these facilities should not be funded by Australian Government funding programs.

#### Guiding considerations

- *The ability to invest in human capital and operating costs results in superior service delivery and more efficient, productive and viable research infrastructure facilities.*
- *Funding for specialist staff assists in developing and maintaining the highly-skilled work-force required for the efficient operation of sophisticated facilities.*

- *Rigorous, consultative project planning is a key input to developing excellent research infrastructure facilities, particularly at the national and landmark scale*

### Prioritisation

- Any proposed research infrastructure investment should align with and support Australia's research, innovation and infrastructure priorities.
- Funding for Australia's research infrastructure should focus on areas where Australia:
  - undertakes world-leading research or innovation;
  - has demonstrated a particular strength in international terms; or
  - has reasons to seek to strengthen capacity in an area of research or innovation.
- Prioritisation of investment in research infrastructure is necessary to ensure appropriate, effective and efficient investment; to support strategic decision-making with regard to national and landmark infrastructure; and to ensure Australia achieves the maximum outcome for the money invested.
- Processes for funding research infrastructure should be transparent, provide effective use of funds and clearly target intended outcomes.

#### Guiding considerations

- *With finite resources, Australia needs to choose where to target its investments in research infrastructure.*
- *Australia needs to consider its priorities in both a national and an international context.*
- *Transparent processes to determine priorities will lead to better informed and more widely supported outcomes.*
- *The strategic identification of capabilities and priorities should be through a consultative roadmapping process every three years.*

### **Excellence in research infrastructure**

- Proposals for investment in all scales of research infrastructure should be evaluated on the basis of their ability to create excellent infrastructure.
- Governance structures should be robust and fit for purpose to ensure the delivery of excellence in research infrastructure.

#### *Guiding considerations*

- *Excellence in research infrastructure is essential to ensuring Australia is able to continue to compete internationally and contributes to a strong innovation system.*

### **Collaboration**

- Funding should favour investments that demonstrate collaborative approaches for the creation and development of research infrastructure and that foster and facilitate a collaborative research culture.

#### *Guiding considerations*

- *Collaboration is a key driver of innovation and is critical to ensuring the research community can deliver the outcomes Australia needs.*
- *There are often economic and efficiency benefits from taking a collaborative approach to establishing and operating research infrastructure.*

### **Co-investment**

- Co-investment in research infrastructure is desirable as it demonstrates a commitment by the investing party/ies to the project. Any program requirements for co-investment should be flexible to leverage maximum support.

#### *Guiding considerations*

- *Flexibility and transparency in co-investment requirements can lead to greater overall leverage and improves the ability of States and Territories to coordinate support for research infrastructure with the Australian Government.*

- *Opportunities for industry co-investment in research infrastructure facilities should be clear and encouraged as a basis for closer research collaboration.*

### **Access and Pricing for Australian-based infrastructure**

- Research infrastructure at the national and landmark scale should be made widely accessible to publicly funded researchers.
- Research infrastructure at the local scale should be made accessible to the extent possible in order to maximise use and support collaboration between institutions.
- Pricing policies for research infrastructure should be clear and transparent and allow for flexibility in the charging model, while still maximising the public benefit.
- Access to and pricing of finite research infrastructure resources should be based on a combination of factors including merit, co-investment, the role of the host institution, opportunities for early career researchers, and supporting collaborative research.

#### *Guiding considerations*

- *An effective access regime ensures that research infrastructure is put to optimum use and fosters collaboration both nationally and internationally.*
- *An effective pricing policy for publicly funded research infrastructure ensures that meritorious research is not priced out of the market.*
- *Clear and transparent pricing policies allow for access costs to be built into research funding proposals.*

### **Access to overseas-based infrastructure**

- Research infrastructure funding programs should consider Australian membership of, or contribution to the construction of, overseas facilities as the development of infrastructure in Australia is not always the most cost-effective solution to providing research infrastructure.
- Research funding programs should consider requests for funding Australian researcher access to overseas facilities.

- Where possible Australian research infrastructure facilities should be encouraged to provide access to International researchers to foster international links and collaborations and build local skills.

*Guiding considerations*

- *Funding access to overseas-based research infrastructure ensures Australian researchers can utilise the best infrastructure available and furthers Australia's engagement with the global research community.*

**Evaluation and Monitoring**

- Research infrastructure funding programs should incorporate procedures for regular and rigorous monitoring and evaluation to ensure the effective use of public funds.

*Guiding considerations*

- *Evaluation and monitoring is essential to determine whether the research infrastructure has delivered its desired outcomes and achieved its objectives over the short and medium term, as well as over its whole life-cycle.*
- *Consideration of whether the research infrastructure continues to be a national priority is assisted through rigorous evaluation.*

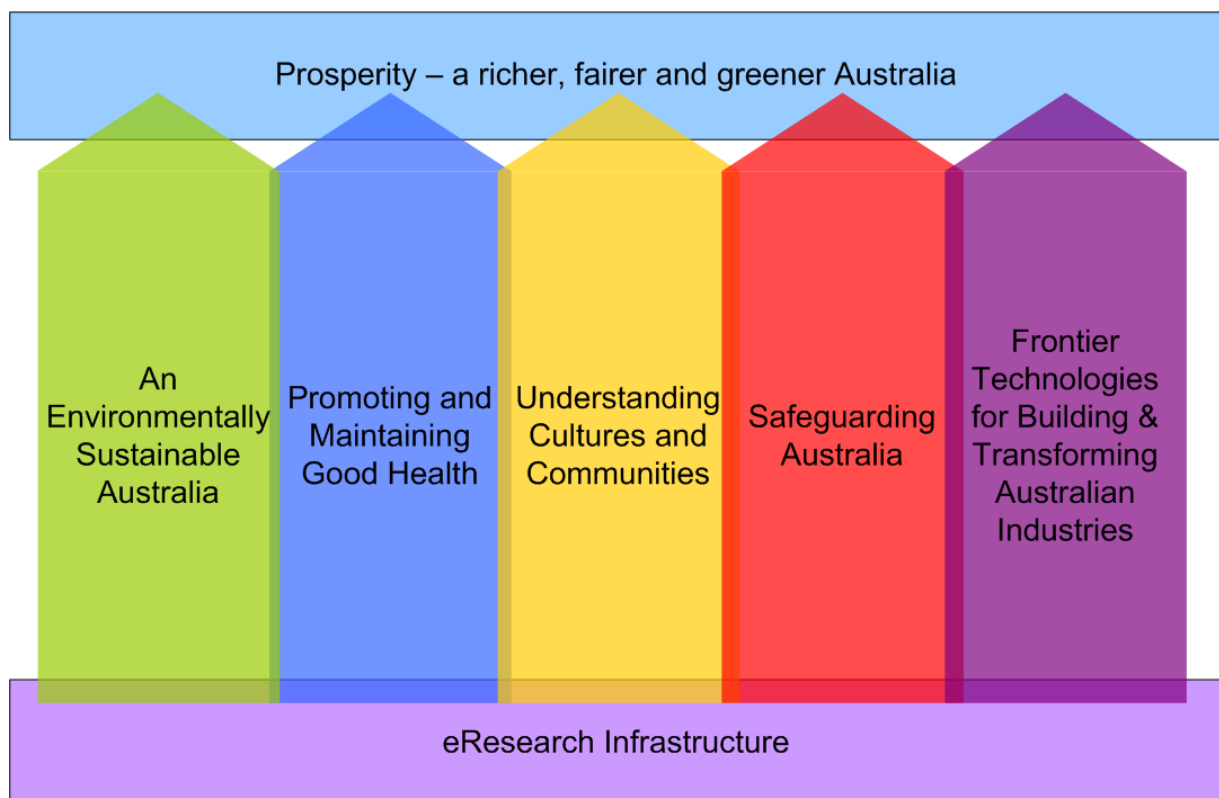
## Capability areas

The 2011 Roadmap outlines research infrastructure capability areas required to support excellent research across priorities areas. The outcomes from this research will contribute to our economic development, social wellbeing, environmental sustainability and ultimately Australia's prosperity.

The capability areas described in the 2011 Roadmap all contribute in a multitude of ways to Australia's National Research Priorities (NRPs)<sup>22</sup>. The NRPs are areas of particular importance to Australia in which a focussed research effort has the potential to improve broader policy outcomes and drive national prosperity. In addition to the four NRPs, the 2011 Roadmap includes an additional research priority, reflecting the importance of research into understanding cultures and communities.

eResearch infrastructure is now recognised as a pervasive and underpinning requirement needed to support all research and research collaboration.

Figure 2 – Diagram of research priorities



In order to highlight the research priorities each capability area contributes to, graphical icons representing each of the NRPs and Understanding Cultures and Communities have been included under the title of each capability area. The legend for these icons is shown below.

<sup>22</sup> <http://www.innovation.gov.au/AboutUs/KeyPublications/Documents/InnovationPortfolioFactSheets.pdf>, pg 140



An Environmentally Sustainable Australia



Promoting and Maintaining Good Health



Understanding Cultures and Communities



Safeguarding Australia



Frontier Technologies for Building & Transforming Australian Industries

The capability areas identified in the 2011 Roadmap clearly contribute to more than one research priority, which demonstrates the benefits of a national, collaborative approach to research infrastructure investment. In addition, it highlights the complex interactions between capability areas, which are needed to deliver comprehensive and effective research infrastructure to solve multidisciplinary problems. A summary of the capability areas' relationship to research priority areas is on page 19.

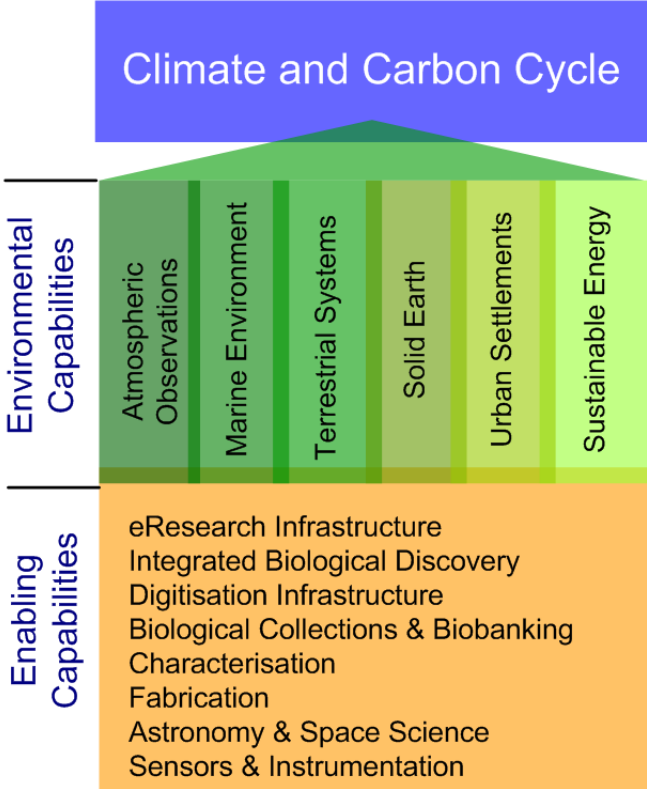
Harnessing and integrating existing and future investment across diverse research domains is essential if Australia is to effectively tackle complex and cross-cutting challenges. In addition, there must be a high level of global connectivity to ensure Australia maintains international visibility and engagement with global research efforts. Therefore, a clear requirement going forward is greater collaboration and integration between research infrastructure providers. This could be driven through the identification of instances of multi-disciplinary research problems that will require the use of research infrastructure from an array of capabilities.

In order to illustrate this, the Roadmap includes a number of examples of cross-cutting issues which will require significant collaboration between research infrastructure facilities. These are identified in the Roadmap as examples describing key areas that require an integrated approach and include: Computational Science (page 28), Sensors and Instrumentation (page 35), Coastal Systems (page 67), and Climate and Carbon (page 75). These examples provide a useful lens through which to consider prioritising specific future investments within the individual capability areas.

It is also recognised that stronger interlocking of infrastructure will depend on both investment in physical infrastructure and a shift in focus to the linkages that infrastructure service providers have with each other and with other members of the research community.

An example of how the cross-cutting linkages and dependencies between capabilities may contribute towards addressing the specific challenge of understanding climate and the carbon cycle is depicted in Figure 3.

Figure 3 – Example of cross-cutting linkages and dependencies



**Summary of the capability areas' relationship to research priority areas**

	<b>An Environmentally Sustainable Australia</b>	<b>Promoting and Maintaining Good Health</b>	<b>Understanding Cultures and Communities</b>	<b>Safeguarding Australia</b>	<b>Frontier Technologies for Building &amp; Transforming Australian Industries</b>
<b>eResearch Infrastructure</b>	✓	✓	✓	✓	✓
<b>Characterisation</b>	✓	✓	✓	✓	✓
<b>Fabrication</b>	✓	✓		✓	✓
<b>Digitisation Infrastructure</b>	✓	✓	✓	✓	✓
<b>Integrated Biological Discovery</b>	✓	✓		✓	✓
<b>Biological Collections and Biobanking</b>	✓	✓		✓	
<b>Integrated Biosecurity</b>	✓	✓		✓	
<b>Population Health Research Platforms</b>		✓	✓	✓	
<b>Translating Health Research</b>		✓			✓
<b>Astronomy and Space Science</b>	✓			✓	✓
<b>Sustainable Energy</b>	✓				✓
<b>Cyber Security</b>				✓	
<b>Cultures and Communities</b>	✓	✓	✓	✓	✓
<b>Marine Environment</b>	✓			✓	
<b>Terrestrial Systems</b>	✓			✓	
<b>Solid Earth</b>	✓			✓	
<b>Urban Settlements</b>	✓	✓	✓	✓	
<b>Atmospheric Observations</b>	✓				

# eResearch Infrastructure



## ***Description***

eResearch infrastructure comprises the information and communications technology (ICT) assets, facilities and services which support research across the innovation system and which maintain the capacity of researchers to undertake excellent research and deliver innovation outcomes. eResearch infrastructure increases both the efficiency and effectiveness of research and opens up new and innovative research possibilities.

eResearch infrastructure is required to provide increasingly powerful computer-enabled simulations and modelling; and an avenue to manipulate, manage, share, integrate and re-use the increasing volume and complexity of datasets and collections across a range of research disciplines and complex problems.

eResearch infrastructure is also required to effectively leverage linkages between increasing sources of data, including those in government or private repositories. Insights from shared research data across disciplines and sectors are needed to drive future innovation.

Additionally, eResearch infrastructure is necessary to manage data, and the results drawn from data, as well as the creation, coordination and management of the software and tools to manipulate and utilise this data.

Planning for future eResearch infrastructure builds on the near-ubiquitous deployment of high bandwidth research networks; on investments in, and excellent uptake of, high performance computing; and growing understanding and uptake of data management practices. The impact of collaboration tools and resources is being reinforced while the use of authorisation services is well established and growing.

While investments at a national scale are positively impacting researchers, these opportunities will need continued support as the demand scales up. This reflects the fact that eResearch infrastructure is an integral part of modern research.

## ***Strategic Impact***

Some of the key opportunities arising from investment in eResearch infrastructure include global competitiveness in research, productivity driven by efficiencies and effective use, faster processing and deeper collaboration, discoveries that were previously unfathomable, and the ability to grapple intelligently with vast amounts of research data.

The rapid transformation of research by ICT-based research infrastructure has shifted from a focus on early adopters and key areas to an almost-ubiquitous experience at all levels of research. In part, this is due to the established eResearch foundations across the country, in national or state-based initiatives.

There is now significant acceptance by researchers and others that the opportunities generated by previously unimaginable amounts of data can only be realised through the use of an eResearch infrastructure capability. This requires both a foundational eResearch infrastructure base and eResearch solutions designed for specific domains.

In a digital age, developments in eResearch infrastructure complement broader initiatives, such as the National Broadband Network and the Australian Government's development of a *Strategic Vision for the Australian Government's use of ICT*<sup>23</sup>. In particular, research productivity enabled by ICT is matched by gains in research-related outcomes, such as policy.

Important efficiencies arise for the researcher, the research institution and the overall research fabric from the ability to conduct research in more seamless and more connected ways, and from a greatly enhanced information base. There is also the potential to stimulate economic growth through research gains in industry, such as in marine resource development and in the attraction of international researchers, research organisations and international facilities to Australia.

There are risks in not supporting ongoing investment in eResearch Infrastructure, including the potential of losing research data of current and previous eras, either through actual disappearance or the inability to discover the data or its relevance. The risks of duplicating data collection and not being able to process and understand research data in real-time to resolve urgent or immediate issues are also high. All these risks impact negatively on productivity, the quality of research and on the actions of decision makers.

In a highly competitive world, ensuring the international significance of Australia's contribution to research relies on our ability to harness the tools that make the data meaningful to the researcher, the user and the policy maker. Our ongoing ability to lead the world and make unique and major contributions to key research areas will rely on continued investment in eResearch infrastructure.

### ***Challenges and assumptions***

In framing the path ahead for continued investment in eResearch infrastructure, it will be essential to ensure that both existing and new eResearch infrastructure can inter-connect with each other and across capabilities in ways that bring about highly developed solutions and support research excellence in meaningful ways.

The next stage of implementation must:

1. ensure the investment framework is flexible enough to support new and emerging priority areas and respond to advances in technology
2. build stronger coordination across the eResearch fabric, and ensure that national investments continue to complement and support the development of state and territory and institution based eResearch capabilities
3. enable a deep integration of eResearch across Australia's research community, including the need for enhanced support for skills capacity development and recognition.

A key challenge when setting priorities will be to balance the way generic (such as collaboration tools) versus specific (such as high performance computing for climate science) eResearch infrastructure is supported.

Balancing support for high end users while also providing the e-fabric that will lift the participation of the many disciplines that are relatively late adopters of eResearch is another challenge.

Meeting these challenges is necessary to ensure that the impact of eResearch is felt across the research sector including between and within individual research disciplines.

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<sup>23</sup> <http://agimo.govspace.gov.au/2011/04/13/ict-strategic-vision/>

Additional trends that will pose challenges and opportunities include:

- Cloud computing will require issues associated with interoperability between public and private clouds to be addressed and increases the demand for enhanced international connectivity and for solutions to sovereignty and privacy issues.
- The rate of data growth including data produced from scientific instruments, streaming and mobile devices and digitised information will outstrip reductions in storage costs. The scale of data storage required now and into the future, particularly as open access to research data increases, has implications for funding continuity and the need for data management infrastructure. The huge opportunity presented by data integration and re-use compounds these trends as will the need to manage the links between data and publications (and in some cases computation models).
- The need for appropriately secure, open and user-friendly access to eResearch infrastructure will accelerate over the next five to ten years. Researchers will need to be enabled to manage their own collaborative research environment, in which they will be able to move seamlessly from and between desk-top computing, mobile technologies, particularly hand held devices, high performance computing and cloud computing. For example, mobile technologies are evolving and will increasingly allow researchers to connect to their experiments, data and analysis tools from anywhere at any time.
- The computation codes developed in some research communities and some data sets being created are now of a scale to be considered infrastructure in the same sense that a telescope or research vessel is infrastructure.
- Automated facilities will drive the growth of workflows and portals, as well as access to highly skilled and specialised research capability and services. In the future, these interfaces may become more like social networks supporting many communities of interest.

## ***Requirements***

### ***Broad Requirements***

The development of eResearch infrastructure in Australia requires a sustained, coordinated, flexible program of funding to provide the long-term platform for the significant transformation in research approach and behaviour that is required to capture the substantial benefit of eResearch.

There is a clear requirement for a coordinating component in eResearch infrastructure development and implementation. Efforts to increase coordination and collaboration, build economies of scale and reduce fragmentation across the eResearch Infrastructure fabric will help to ensure that the benefits delivered by eResearch are delivered across the research sector, and consolidated and maintained in the longer term. Principles that could underpin the development of a coordination mechanism include:

- enabling communication and engagement between researchers, projects and programs, industry, institutions and agencies engaged in accessing and supporting eResearch and eResearch infrastructure
- coordination around important issues such as policy, research community and institution engagement, interoperability and implementation phasing and approaches
- extending and complementing ICT and eResearch support in institutions and by state and territory governments; including allowing for the evolution and migration of services over time from within institutions to external service providers, or from research budgets to organisational ICT budgets

- facilitating and encouraging government agencies, funding agencies and research institutions to continue to build eResearch infrastructure visions and plans together
- clearly identifying roles and articulating the space where continued capital investment should continue, and where other methods of providing eResearch infrastructure capability should emerge.

While some researchers advance readily into an eResearch-enabled world, it is important to assist other researchers to better appreciate the benefits and to engage with eResearch infrastructure. The reality is that many researchers wish to benefit from a seamless experience of eResearch infrastructure without necessarily knowing how the infrastructure works.

In addition, the interface between investments should be easily accessible and usable, irrespective of how many individual initiatives or programs underpin the service, and in a way that supports a seamless balance between vertical (discipline or demand driven research) and horizontal requirements (data, software and/or compute).

In a specific discipline, such as astronomy, it is important to be able to move vertically to access data management, software, various compute and networking requirements without having to work with different horizontal initiatives.

Equally, it is critical to ensure horizontal integration and management, for example a cross-discipline capability in data management which can respond to the needs of individual researchers allowing new research that previously could never have been envisaged.

Ultimately, the aim should be to coordinate and position eResearch initiatives to provide broad, deep and well integrated support to the researcher that facilitates a seamless interaction between institutional resources, national eResearch infrastructure initiatives and other eResearch service providers.

### ***Specific Requirements***

The following specific requirements recognise that the investments currently in place must be built on and, as appropriate, extended to support further advances.

#### ***Data***

eResearch infrastructure investments to date have made important headway towards addressing data management, data sharing, access and availability across and between research institutions including dealing with issues associated with data capture, aggregation, transmission, storage, access, re-use and curation. The significance and importance of data have also been recognised throughout the 2011 Roadmap.

Australia's ongoing research success will depend on the development and improved management of national and global research data environments, as well as the engagement of researchers and research institutions in improving and supporting data management initiatives.

The significant increase in the rate of data being captured, the range of disciplines and capability areas depending on data and the substantial potential benefit offered by integrated data analysis and re-use require more coordination across initiatives and between stakeholders.

Recent initiatives have positioned Australia well globally, but we need to move towards a national research data management framework that links data, publications and related information. This must include:

- an holistic approach towards the creation, integration and management of research data repositories as part of the broader national scholarly information infrastructure, including

common data access and data movement infrastructure that is open to both the producers and consumers of research data

- guidelines to deal with issues related to policy, ethics, ownership, access, privacy and security
- access to research-significant data collected and held outside research institutions, for example, by the Australian Bureau of Statistics, the Australian Institute of Health and Welfare and the National Archives of Australia
- coordination of appropriate access to both research and administrative data sets
- consideration of including a requirement for data management plans and embedding the data management framework into funding grant rules
- the development and use of research tools, particularly in the areas of automated metadata, access, data movement, data linking, analysis, visualisation and data mining techniques; all of which will further the aim of data re-use
- recognition of and support for the links between data and publication, and in some cases computational models or other tools.

In addition, the support of institutions is needed to:

- put in place automated metadata capture and data publication frameworks
- facilitate the export of data to repositories and between institutions and data intensive facilities
- raise awareness of eResearch across many disciplines. This will be fundamental to capturing the significant benefit of existing and new investments.

It will be critical in developing a national research data management framework to recognise the foundational role of existing eResearch infrastructure investments, in particular in data management and data storage. The sector will need to coordinate and, where necessary, require and reward the necessary changes in practice. An aspirational aim could be to ensure that by 2020 all appropriate data will be captured and discoverable at the time of creation and that initiatives will be well advanced to deal with already existing data sets, collections and publications.

### ***Digitisation***

Digitisation is a requirement for a broad range of research disciplines and includes non-electronic data and non-traditional research materials, as well as digitisation of historical records and older paper-based research collections.

This is further discussed in the Digitisation infrastructure capability. To maximise benefits of any future digitisation initiatives, it will be essential to align them with the proposed research data management framework.

### ***High Performance Computing***

Demand for national high performance computing (HPC) infrastructure, which underpins problem-solving methodologies across a broad range of research domains, continues to grow at significant pace. Globally, this can be seen in moves towards exascale approaches to computing. To support HPC infrastructure while preparing for exascale computing, Australia requires:

- continuing investment in consolidated peak HPC capability

- specialised computational support to find solutions to challenges such as achieving close coupling with unique digital instrumentation, data collections and integration of unique computational methods
- development of scaled hardware
- flexibility to buy processing capability from commercial cloud service providers, where appropriate
- support for the ‘new breed’ of computational experts required for exascale computing
- specialist HPC facilities for particular research communities, where there is genuine national need. However, these should not be developed independently of investment in consolidated peak HPC capability.

A strategic assessment will be required to determine if Australia should develop its own exascale capacity or consider collaborating internationally to enable access to such a capacity for Australian researchers. However, a continued strong on-shore infrastructure presence is necessary if Australia is to develop and retain the expertise that is critical to advances in computational science and HPC.

Support for ongoing human capacity and expertise in HPC is a critical component and includes expertise in peak services as well as allowing national capabilities to become comprehensive service providers of high-end services.

Investment centred on data centric computing rather than compute centric capacity is also an important consideration. Data-intensive workloads are the new paradigm in technical computing, driven by exponential data volume growth from all kind of sources such as telescopes, satellites and high-resolution scientific instruments. Other requirements could include the following:

- Simulation software which might include large complex suites of software codes and libraries. Software codes, which are often discipline specific, could be accessed in the same way as international research infrastructure. A case may exist for their purchase to be considered as part of infrastructure investment, where they come with substantial recurring costs.
- Visualisation is required for most scientific and other disciplines using computational or data resources. With larger and more complex simulations and data sets, visualisation will continue to be the essential user interface to extract results and insights.

### ***Software, Tools and Collaboration Resources***

Software, tools and collaboration resources enable researchers to access, annotate and analyse large-scale, distributed datasets, as well as ingest, manage, annotate, analyse, share and publish their own data. To allow effective collaboration it will be critical that many of these software tools are standardised and effectively managed.

Shared online spaces empower researchers to work with each other and more easily share and access global resources, including through software, common tools, web and video collaboration. In addition, shared collaboration spaces 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 number of related issues will need increasing attention:

- continued promotion and ubiquitous adoption of authorisation and authentication measures, underpinned by ‘single sign-on’ approaches. While significant advances have been made in this space, the reach of such measures needs to extend to holders or

providers of data relevant to research beyond public research organisations, such as government and commercial eResearch service providers

- more sophisticated software and tools will need to be developed, deployed and standardised to enable data analysis, modelling, mining, simulation and high resolution visualisation. As data sets increase in size, having tools that can effectively merge or enable researchers to work across the data sets will become increasingly important
- development should continue in a mixture of both case-specific and general eResearch infrastructure tools, software, services and resources, including making them ready for exascale computing.

Many tools are available internationally or commercially, and serious consideration should be given to accessing these where possible.

Where data understanding or interpretation is contingent upon software, it will be critical to build sustainability into the software development process. Software creation is a discipline, as is data curation, and the development of software and tools must:

- adhere to industry standards and architectures to avoid duplication and ensure re-use and interoperability
- integrate into national mechanisms which allow sharing of software and tools, such as an 'apps store' to enable researchers to work directly with multiple data sets as a user, and which foster software skills development
- seek to develop metadata around software, as well as data, so that it is discoverable
- recognise that researchers also require skills to use the software
- embed collaboration tools, software and resources into routine activities of researchers.

### **Networks**

The Australian Research and Education Network (AREN) is an advanced optic fibre research and education network that connects universities and research institutes in all capital cities, many regional centres and isolated research facilities such as radio telescopes, as well as connecting Australian researchers to international collaborators.

A comprehensive, cooperative and non-competitive approach to network strategy, operations and capacity planning is essential. In order to facilitate this, AREN providers<sup>24</sup> must collaborate to deliver interoperability and interconnection between their respective networks.

Future strategic development of the AREN should focus on:

- continued extension of the reach, redundancy and scalable capacity of the national backbone with a priority focus on known and anticipated research demand,
- provision of higher level overlay networks for specific research communities to support the development of higher order applications and services
- enhanced international network capacity, including high quality eastern and western seaboard access to ensure redundancy
- greater interoperation between AREN service providers and commercial networks, including the integration of broadband wireless research and data collection sensor networks into the core network

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<sup>24</sup> These include AARNet, VERNet and SABRENet.

- enhanced connection of researchers and a range of public and private research organisations to the AREN, including access to the resources held in these institutions that can be shared for research use.

To underpin large science initiatives, leverage existing investments and build on the capability of multiple service providers, future investment must, wherever possible, engage both network infrastructure providers to the AREN and to broader network initiatives in Australia.

At all times the use of existing network infrastructure investments should be optimised with the expectation that network partners will collaborate to ensure new networks are not built where current capacity exists. New funds can then be directed to the creation of special services where service provider capabilities are not otherwise available.

### ***Human capital***

Australia's capacity to deliver internationally competitive research will increasingly rely on developing the skills necessary to support and capitalise on eResearch infrastructure. Return on investments in research infrastructure could be increased by a focus on enhancing:

- expertise available to develop, run and manage the infrastructure
- mechanisms to engage ICT specialists in e-Research projects with domain-based researchers
- the number of ICT specialists available to support researchers , as well as recognition and development of career paths for individuals with high-level ICT skills as providers of technical support for research communities.
- initiatives to upgrade the skills of researchers to enable their use of eResearch infrastructure
- skills of researchers and students across disciplines to manipulate and analyse large databases, and adapt software to address domain specific research questions.

The issues around researchers' expertise and ICT literacy will need to be considered in the broader research policy context.

### **Example: Computational Science – need for an integrated approach**

Computational science is a multidisciplinary field that uses advanced computing capabilities to understand and solve complex problems. It employs mathematical models and quantitative analysis techniques in computer simulations of problems in various research fields and in many it is recognised as a third route to discovery, sitting alongside experiment and theory.

Often events simulated in computations are too fast, small, large, complex or dangerous to be amenable to experimental investigation, such as the motions of molecules, economic processes or predictions of future climate. Simulation and modelling are also central to modern engineering practice. Computational engineering, for the design and optimisation of new products and processes, is now pervasive across technical and consumer products and major industrial and societal infrastructure.

The pace of technological developments in computer hardware has been unrelenting for decades. This can be expected to continue and will require energetic efforts to develop new algorithms and software to capture the performance of emerging hardware platforms. Surmounting these challenges will open up new performance horizons for researchers using computational methods, and ultimately enable new discoveries.

As a new era in algorithms and simulation codes begins, it is essential that Australia's next generation of researchers are provided with a path to the frontiers at which their international collaborators are working. Specifically there is a need for integrated hardware and software systems, algorithms, visualisation tools and computer code libraries to be provided in an integrated, coherent and generally accessible manner. This will need to be accompanied by appropriate training and educational programs. Most critical is a clear focus on research user needs and usability of the technologies.

The eResearch infrastructure and Fabrication capability areas provide essential support for computational science. In turn, computational science supports many of the capabilities set out in this Roadmap, including Astronomy and Space Science, the bioinformatics and biostatistics aspects of Integrated Biological Discovery, Characterisation, and the environmental capabilities.

# Characterisation



## **Description**

Characterisation is the direct analysis of the microstructure and microchemistry of materials. Materials may be soft (tissue, cellular, polymeric) or hard (metals, ceramics, semiconductors). Analysis incorporates imaging, spectroscopy and scattering processes, and includes studies of morphology, dispersion, structure, composition and bonding. Characterisation is recognised as a platform technology that is essential for many research disciplines.

There is a continuing need to enhance infrastructure in this capability to ensure Australian researchers can continue to work with state-of-the-art technology. These enhancements are likely to include adding a temporal dimension to allow dynamic processes to be probed in real time, and the combination of measurement modalities so that varied materials' properties can be simultaneously measured at high resolution.

## **Strategic Impact**

The Characterisation capability plays a key role in research across the physical, engineering, life and environmental sciences. It underpins many fundamental research efforts and the development of new and emerging technologies. From atoms to molecules and crystals, from cells to tissue, through to entire organisms, characterisation enables research between many disciplines, including archaeology, zoology, materials science, medicine, life sciences and geosciences.

Characterisation infrastructure allows scientists, engineers and industrial researchers to understand and quantify diverse materials, both manmade and biological. As well as having the ability to design and develop advanced materials, Australia needs to be able to develop high-performance processing routes with low environmental impact for existing materials.

The pervasive nature of this capability area is exemplified by its application in the resolution of important and diverse research questions. This is evident through examples such as the use of electron microscopy to determine the 3D structure of human islet/beta cells to provide insight into diabetes, and the use of the focused ion beams to obtain the structural morphology and elemental composition of particles recovered from crime scenes, to assign a possible source for this evidence.

## **Challenges and Assumptions**

Previously funded facilities have a strong history of collaborative and integrative provision of infrastructure; this should be encouraged across the entire characterisation capability. Where possible, collaborative links to other capabilities, including fabrication, should be enhanced. This could include networks of people, information and communication technology and cross-research infrastructure engagement.

To ensure the full scope of this capability area is covered, facilities should be widely accessible. Future funding should serve the research and innovation system broadly encouraging collaboration between universities, government, independent and private sector organisations. Moving into the future, there should be a balance of centralised and distributed facilities to support accessibility and collaboration.

Modern characterisation instrumentation requires a high-level of specialist expertise to obtain excellent data. As characterisation grows in complexity in order to address more challenging research questions, the gateway to discovery will shift from the instruments themselves to the subsequent offline visualisation, analysis and simulations required to deal with increasingly large and multidimensional datasets.

In order to manipulate the complex large-scale datasets produced by this capability, it will become increasingly important to have specialised computational modellers, expert data analysts and biostatisticians, in addition to expert technical staff to support the instruments.

In Australia, the uptake of combinatorial and high-throughput experimental methodologies has been slow outside of the life sciences and addressing this will be a future focus.

A challenge exists to build on the world-class platforms established to date, such that they are transformed to operate at higher spatial and chemical resolutions, in all spatial dimensions and real-time. Further challenges lie in providing integrated expertise and instrumentation, genomic characterisation and high-throughput screening.

This capability will benefit from strong linkages and interaction with the Fabrication capability, along with the Integrated Biological Discovery capability.

### ***Specific Requirements***

The highest priority is continued support for current facilities and expanding them to realise the benefit from recent advances in certain characterisation technologies.

#### ***High-level Microscopy and Microanalysis***

Advanced microscopy and microanalysis is a key enabler for world-class research outcomes across numerous disciplines. Future investment should be guided by user demand and usage, and next-generation equipment development and ensuring broad based access.

Given Australia's international strength and proven track record in high-resolution cryo-electron microscopy investment in this area could be considered.

#### ***X-ray techniques (Synchrotron science)***

As an enabling facility, the Australian Synchrotron provides essential infrastructure that supports research across the entire sector.

The Australian Synchrotron currently has eight world-class beamlines. A ninth beamline, which is under construction, will be a world-leading facility for health and imaging sciences and support a clinical research program.

Further investment should include ongoing support to enhance the facilities capacity to service the needs of the research sector. Any further funding could support additional beamlines, such as an earth science beamline, upgrades to the current accelerators or major upgrades to the existing facilities. In addition, further support for Australian researchers to access international Synchrotrons should be considered.

Investment planning should take account of the 2010 Science Case for the Development of the Australia Synchrotron<sup>25</sup>, as well as international trends in synchrotron science, existing strengths and demand for synchrotron science in the Australia.

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<sup>25</sup> <http://www.synchrotron.org.au/index.php/about-us/australian-synchrotron-development-plan>

## ***Imaging***

Increased capacity and ongoing support for existing facilities at a level that enables them to continue as world-class is required. Imaging is a rapidly evolving field and whilst hardware can be upgraded, it is often more effective to purchase new systems as they become available.

A range of imaging technologies will allow the strengths of different modalities to be exploited, for example to give more accurate diagnosis and monitoring of disease. Support for magnetic resonance imaging (MRI), positron emission tomography (PET) and other molecular imaging modalities such as single photon emission computed tomography (SPECT), optical (luminescence and fluorescence), ultra-sound and THz imaging should be considered.

Investment in extreme field imaging will support biomedical research and position Australia to lead developments in cutting edge physics, engineering and imaging applications.

Establishment of a multi-modality human imaging and therapy research facility could also be considered. The facility would enable biomedical and clinical scientists to implement new therapies and assess their efficacy and side-effects using the most advanced imaging technology available. This facility would build on the complementary and simultaneous use of different imaging techniques.

Consideration should also be given to support nuclear magnetic resonance (NMR) spectroscopy which is an essential platform technology for research in molecular and material sciences, for example, chemistry, structural biology and metabolomics.

## ***Neutron science***

The addition of a positron beamline to the Open Pool Australian Lightwater (OPAL) reactor at the Australian Nuclear Science and Technology Organisation (ANSTO) would enable fundamental studies in PET and should be considered with reference to ANSTO's 2010-2015 Corporate Plan<sup>26</sup>. This capability would contribute to medical diagnostics and therapy, along with other biological and commercial applications.

## ***High-throughput and combinatorial materials science***

High-throughput methods in research involve integrated, often highly automated, facilities for synthesising libraries of new materials and testing a range of characteristics in parallel, rather than in series as is traditional. In general, the equipment required for high-throughput and combinatorial approaches to materials discovery differs from the equipment available in current characterisation facilities.

High-throughput and combinatorial materials science is an emerging area, with potential for a large user base, which will enable the advanced materials discovery process to be markedly sped-up<sup>27</sup> and infrastructure to support this area should be considered.

## ***Heavy-ion accelerator science***

Current heavy-ion accelerator facilities are engaging in a broad range of cross-disciplinary collaborations and research, for example radiocarbon dating and soil analysis. These facilities contribute to various research areas including nuclear physics, materials research and characterisation.

The Characterisation capability could be expanded to include the characterisation components of heavy-ion accelerators. This would involve support for the development and operation of beamlines and end-stations for ion-beam analysis of materials.

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<sup>26</sup> [http://www.ansto.gov.au/\\_data/assets/pdf\\_file/0005/49199/ANSTO\\_Corp\\_Plan\\_Final-bookmarked-tagged2.pdf](http://www.ansto.gov.au/_data/assets/pdf_file/0005/49199/ANSTO_Corp_Plan_Final-bookmarked-tagged2.pdf)

<sup>27</sup> An example is the National Institute of Standards and Technology Combinatorial Methods Centre in Maryland, USA. [www.nist.gov/mml/polymers/combi.cfm](http://www.nist.gov/mml/polymers/combi.cfm)

## Fabrication



### **Description**

The ability to synthesise advanced materials, fabricate device components and produce prototypes is vital to increasing the innovation dividend from Australia's investment in basic materials research, solving problems in diverse research areas, and progressing research outcomes to market through engagement between industry and the research community.

Facilities for nano, micro and macro fabrication are required to enable researchers to understand the structures and properties of new classes of materials, progress the technology development and demonstration of products and processes, integrate and package components for a wide range of devices and provide new commercial products.

The Fabrication capability is fundamental to pervasive, cross cutting research challenges as it provides the necessary tools for research undertaken in a variety of areas such as defence, and medical and biological disciplines.

### **Strategic impact**

Nano, micro and macro scale fabrication infrastructure provides researchers with the tools necessary to advance technologies which contribute to improved health, safety and communication.

The research sector will benefit from an increased focus on integrated fabrication solutions. For example, the interaction between biology and soft matter with the traditional inorganic hard matter device technologies will underpin applications in bionics, sensors, plastic electronics and drug delivery. The fabrication of quantum/nano-scale photonic, electronic and electromechanical structures, and nanoparticulates, will have a major impact on all areas of information and communications technology and sustainable energy technologies, as well as defence and security systems.

Nanotechnology in photonics, electronics, bio-platforms, and microelectromechanical systems research remains a priority, with massive growth predicted.

Advanced fabrication infrastructure will provide a platform for areas that may have a significant impact including: metamaterials, photovoltaics, robotics, bioengineering, bio-materials, sustainable energy technologies, hybrid glass and multi-material optical fibres, integrated nanophotonics, functionalised nanoparticles and nanolayers. Fabrication enables the linking of engineering and biomedical sciences, including biomedical devices and biomimetics. Basic research in the applied science and engineering areas of quantum computing, quantum and quantum-atom optics will also be supported by an enhanced fabrication capability.

### **Challenges and assumptions**

To expand and enhance research outcomes in the Fabrication capability, researchers require access to local, well coordinated, integrated, state-of-the-art facilities, supported by expert technical staff. These facilities should comprise the full research product value chain, from advanced materials design to materials synthesis, through to the processing of devices to packaged prototypes.

The inherently different requirements of academic and industry researchers should be balanced in this capability by considering the flexibility of fabrication tools, industry-readiness and the need for reproducible and reliable processes and quality control.

There is an opportunity for greater interaction to obtain synergies across existing capabilities. For example, state-of-the-art characterisation capabilities are critical to the fabrication of devices and materials. Successful collaborations should be built upon into the future. Facilities should also be encouraged to broaden their user base, for example through increased visibility in the research community.

An increased focus on integrated, cross-disciplinary research in areas such as nanotechnology, photonics and biotechnology warrants consideration of the benefits and opportunities that may arise through co-location of certain fabrication facilities with capabilities in characterisation, health discovery and translation, sustainable energy, and defence and security. This will enhance cross-disciplinary collaboration, reveal new areas for investigation and facilitate the development of industrial applications.

Upcoming engineering challenges, such as the effects of climate change in urban environments, present the need for the development and enhancement of novel methods of fabrication, materials development and engineering processes.

### ***Specific Requirements***

Continued support for existing fabrication facilities is a priority. In addition, the alignment and/or grouping of downstream facility chains and related capabilities should be considered. Ongoing replacement of tools will be required along with investment in new equipment.

Research facilities should include cutting-edge equipment and cleanrooms, and expert personnel that provide the capability to design, fabricate, process, manipulate, synthesise and integrate advanced materials (including bio-materials) and devices.

A key area that has been identified as requiring particular attention is the current gap in Australia's research capabilities related to the design and synthesis of advanced materials and quantum/nano structures. In particular, breakthrough science, innovation, platform technologies, and intellectual property generation related to devices is increasingly embedded within the design and growth of advanced materials and nanostructures, rather than in the subsequent device fabrication and processing technology. Australia requires facilities for state-of-the-art design, growth and deposition of advanced materials and quantum/nano structures. Priority consideration should be given for this enabling and high impact research capability.

Research outcomes will be strengthened if researchers can design, model, predict and test while manufacturing and packaging prototypes for physical evaluation. Equipment to enable the development and realisation of rapid and complex prototypes will accelerate fabrication research into development and commercialisation, along with experimental testing of concepts with rapid feedback for iterative development. Novel manufacturing techniques such as 3D printing should also be considered.

Prototype fabrication facilities are a gap in current research infrastructure. Advanced materials design and synthesis, sensors and measurement systems, and fabrication, for example, need to converge to provide new prototypes and commercial products. Investment in packaging and back-end fabrication techniques and larger scale metrology facilities will streamline progress to market for innovative materials. The delivery of fully functional, packaged devices and prototypes requires not only versatile equipment platforms but also new expertise. Packaging across multiple length scales is required to enable nano and micro device technologies to interface with real-world systems.

Ion implantation and ion accelerator infrastructure remain a priority, noting that this is also relevant to the Characterisation capability. Specific support for capital investment in beamline instrumentation should be considered under the fabrication capability area. For example, there is a need for development and operation of beamlines, end-stations associated with ion-implantation and associated ion-beam processing.

Support for researchers to access and navigate existing and future facilities is an additional priority. The provision of expert advice to researchers and strengthening the concept and design capacity by coordinating activities across several facilities (in particular in characterisation and fabrication) is necessary to capitalise on earlier and any future investments. This may include the expansion of skills in the current facilities and exchange of personnel and expertise.

#### **Definition of advanced materials**

Advanced materials are materials which, as a result of innovative design, synthesis, fabrication or processing techniques, acquire novel structures or superior properties. There is high demand for materials with step-change improvements in performance to meet major needs in areas such as health, transport, energy, natural and built environments, communication and defence.

Next generation materials will be multifunctional (e.g. biomedical materials that combine targeted drug delivery and medical imaging agents or stem cells and functionalised scaffolds), adaptive (e.g. being able to self-heal when damaged) and smart (e.g. being able to monitor corrosion or strain).

### **Example: Sensors and Instrumentation – need for an integrated approach**

Recent advances in sensors and sensor networks have opened up new approaches to probing our world, and to making decisions based on information gained in real time. There is also an increasing desire for smart technologies to monitor our health, the environment and industrial processes, as well as for defence and security. In addition, Australia has a long-standing reputation internationally for excellence in instrumentation and the application of new technologies, most particularly in areas such as astronomy and biotechnology.

We are living in an era of biology-chemistry-physics-engineering convergence and it is anticipated that many future advances will occur at the interfaces between these disciplines.

For Australia to secure a leading reputation in new sensors, sensor networks and advanced instrumentation in these converging areas, it must build on its established research strengths in materials science, photonics, experimental physics, biotechnology and engineering.

Infrastructure is needed to support research that brings together emerging materials systems and fabrication technologies to create new forms of sensing devices capable of measuring the chemical, biological, or physical characteristics of systems of a diverse range of scales ranging from single molecules to entire ecosystems. Such devices will increasingly need to be capable of multiplexed sensing, of working in real time to facilitate decision making, and of being integrated with other sensing modalities and high throughput techniques.

In order to secure advancements in this vital area, the Fabrication and Characterisation capability areas should be built upon to ensure the necessary infrastructure is provided to support sensors, sensor networks and instrumentation development.

Many of the research infrastructure capability areas across this Roadmap are dependent on advances in sensors, sensor networks and instrumentation. For instance:

- The environmental capabilities rely on the use of sensor networks for sustained observations of the critical components of the earth's systems.
- Advanced instrumentation is vital for securing Australia a significant role in big science projects, particularly in astronomy and space science.
- The use of sensors for medical monitoring applications is an emerging and vital area, particularly in the move to more personalised medicine.
- The development of adaptations and extensions to the suite of 'omics technologies in the Integrated Biological Discovery capability.

Research in sensing and measurement systems offers particular opportunities to achieve broad ranging outcomes across all of the national research priorities as well as strong industry engagement.

# Digitisation Infrastructure



## **Description**

A Digitisation Infrastructure capability is required to build Australia's capacity to enable large collections of artefacts, images, sound recordings, documents, films, animals, insects, plants and geological samples to be accessible in digitised form.

Many collections of national and international significance in the natural sciences, humanities, arts and social sciences are currently available only to researchers who can physically visit their repositories.

A Digitisation capability will be implemented by assembling state-of-the-art digitisation technology and expertise to provide high-throughput digitisation services to the Australian research community to achieve priority research outcomes.

This will capitalise on Australia's investments in eResearch infrastructure to ensure maximum use of Australia's invaluable collections, providing access for remote, regional and global communities and new opportunities for diverse research disciplines.

## **Strategic impact**

The range of disciplines that would benefit from this capability is vast, including biology, environmental science, ecology, zoology, humanities, arts, social science and health sciences. Australia's curators, statisticians, scientists and communities would all interact with this capability.

By enabling greater access to research resources, important research questions will be able to be investigated. Research collections are preserved for use within their original discipline but sometimes their greatest impact can be in another field of research. For example, the availability of digital information from diverse anthropological collections is being used for research into agriculture, biomedicine, control of invasive species and other fields.

Virtual connections between institutions, collections, and communities will enhance inter-disciplinary collaborations through shared creation of digital data and access to the latest instrumentation.

The capability area will also address the urgent issue of the preservation of research material that is known to deteriorate over time. Collections of natural materials such as insects, flora and fauna as well as magnetic tapes, printed documents, artefacts, film and microfilm are inherently prone to damage and decay. There is limited time before these materials become unusable. Appropriately managed and curated digitisation prevents this loss and transforms these research sources into a permanent, durable form.

Digitisation of Australian collections will help ensure that Australian data is incorporated into international studies, influencing both the questions asked and the solutions that are generated. For Australian researchers, increased access to Australian datasets will result in findings which directly reflect Australian situations.

Digitisation will also allow dispersed collections to be studied as a whole.

This capability will increase the scope and reach of Australian research by enabling collections to be discoverable. As well as revolutionising the access to this material by researchers, it will be valuable to the community at large, including citizen scholars. Once digitised, a collection is available to be enhanced, connected and enriched by the wider community.

The capability will augment existing dispersed and incomplete digitised data sets and will promote greater collaboration between many of the capabilities identified in the Roadmap.

The Digitisation Infrastructure capability will also exploit the potential of the broader digital revolution and Australia's investment in eResearch infrastructure.

### ***Challenges and assumptions***

The digitisation of collections is only of benefit if there are structures in place for storing, curating, accessing and analysing the resulting data. This requirement will depend heavily on on-going support for eResearch infrastructure programs. Current eResearch based projects, as well as future projects which may be implemented under the Cultures and Communities capability are likely to be crucial partners with the Digitisation Infrastructure capability. In addition, the implementation of this capability must build on already implemented digitisation projects and digital collections, consolidating previous work and bringing all to a shared standard.

The vast array of collection material and the level of demand for digitisation services will be a challenge in implementing this capability. Extensive consultation with the research community and collection holders will be required to ensure priority is given to the digitisation of collections that are of national and international research significance or are necessary to answer nationally significant research questions.

In addition, issues of access, privacy, intellectual property and copyright surrounding some of the data made available through digitisation will be a challenge. It is anticipated that the majority of digitised collection data would be publicly available as this provides the maximum benefit to the research and general communities. A number of initiatives, such as the National Library of Australia's Trove project<sup>28</sup> and the Museum Metadata Exchange Project<sup>29</sup>, have developed some innovative approaches to these issues which could be drawn on in implementing this capability.

Extensive stakeholder consultation will be needed to ensure optimal selection of technologies and to develop a merit-based process to prioritise collections.

The capability will need to take into account existing digitised datasets and have strong linkages to other capabilities, particularly those of Cultures and Communities, Biological Collections and Biobanking, as well as eResearch Infrastructure.

### ***Specific requirements***

The digitisation technology will need to be chosen to suit the highly varied demands of the user community and types of material to be digitised. Technology may include equipment suited to mass digitisation of objects, automated digitisation of audiovisual recorded material or microfilm, automated equipment suited to paper-based/archival collections, and technology suited to high-throughput processing of organic herbarium and natural history specimens, including those at microscopic scale. 3D technology for both imaging and rendering is anticipated to be routinely used in the near future and scanning of objects using a variety of imaging technologies is becoming increasingly common. Mobile digitisation technology which can be taken to fragile unmoveable and regional collections is likely to become important.

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<sup>28</sup> <http://trove.nla.gov.au/>

<sup>29</sup> <http://www.museumsaustralia.org.au/site/mme.php>

Research infrastructure for this capability area will take advantage of newly developed rapid digitisation technology suited to large scale or mass digitisation. These tools will transform the traditional, labour-intensive processes previously required to make digital data available.

In order to serve the broadest range of users, distributed facility model should be considered. This may include a suite of services, not just the instruments and training, but also the provision of expertise on methodology and interpretation.

# Integrated Biological Discovery



## **Description**

The Integrated Biological Discovery capability is a set of critical underpinning platforms comprising infrastructure for Genomics, Proteomics, Metabolomics and Phenomics (mouse and plant), as well as the pervasive and integral fields of Bioinformatics and Biostatistics. A sophisticated and cohesive national biomolecular capability network is required to ensure that strategically important research is facilitated while promoting the parallel goals of knowledge diffusion and collaboration.

As we move towards understanding biology at the systems level, access to large data sets holding many different types of biological information has become crucial. However, the extensive use of next-generation sequencing and other high-throughput technologies also poses new challenges in coping with and interpreting the vast volumes of data being generated. Bioinformatics and biostatistics capabilities are needed to harness the full potential of this data and allow the integration across platforms.

Systems biology is a highly interdisciplinary field bringing together biologists, engineers, chemists, physicists and computer scientists in an effort to unite information on genes, proteins, interactions and metabolomics pathways, to help understand the function of complex biological systems and how they may be optimised in the context of biomedical, agricultural, food science and environmental applications.

## **Strategic Impact**

The 'omics revolution resulting from completion of numerous global genome projects and the advent of next-generation sequencing capability will enable the sequencing of all organisms/tissues/cells of interest to researchers. Single gene sequencing is no longer the common practice; rather the sequencing of families of genomes is the reality. The scale of data and information being collected is unparalleled in the history of biological research and those nations that can generate, and more importantly, mine this resource will be well placed to reap the rewards that will flow to the health, agricultural and environmental sectors.

The revolution of biological science and techniques currently underway is inherently coupled to the information technology revolution that began in the late 20<sup>th</sup> century. The availability of the required resources to harness the outputs of the technical advances provided by new technologies is the key to achieving the best results in our investments in this area.

Bioinformatics and biostatistics provides the basis to achieve this goal. These capabilities provide the necessary context to data and form the linkages to service the scientific community to best utilise the outputs of advancing technology, both within and across formerly separate domain areas.

Discovery phase research utilising genomics can uncover new biological pathways to better inform drug development and pharmaceutical use. Individualised treatments will be the next goal with the identification of specific biomarkers that can be developed into diagnostic assays. This will improve both health outcomes and the economics of health care.

Mouse models of human disease play a key role in the interpretation of the human variability that currently limits translational medicine. By having available the unique suite of mouse phenomics infrastructure and with existing excellence in both translational medicine and mouse phenomics,

Australian researchers are well equipped to play an important role in the next phase of unlocking the human genome and producing new health treatments.

Large scale studies of agricultural populations have the potential to deliver international competitiveness and environmental sustainability for Australian agri-food industries. Additionally, genomic data will improve the understanding of Australia's unique flora and fauna and the management of Australia's biological heritage in a sustainable manner.

### ***Challenges and Assumptions***

The existing biological capabilities provide a launching pad from which to build a fully integrated biosystems research infrastructure capability supporting environmental, agricultural, medical and biosecurity bioscience areas.

While coordination between component facilities provides centralisation and avoids duplication and fragmentation, several challenges exist including the expansion of the capability into new and complementary areas of research infrastructure to provide essential support for the biosciences.

There is a need for integration between disciplines to deal with emerging and complex issues that are being examined by researchers today. An expanded and enhanced Integrated Biological Discovery capability area will facilitate coordination between the 'omics, bioinformatics and relevant aspects of other capabilities.

However, the platforms must be nimble and open to new technological breakthroughs. They should encourage multi-disciplinary collaborations and links with international peers. Existing infrastructure provides a platform for international collaboration in biomedical research and this should be further built upon.

A continuing challenge in this area will be the lack of bioinformaticians and biostatisticians and the need to embed these skills within biological research groups. Computational analysis has now become a bottleneck for research progress, both in Australia and globally.

The Integrated Biological Discovery capability will be most effective if it has strong linkages with the Characterisation, Biological Collections and Biobanking and Translating Health Research capabilities.

### ***Specific Requirements***

Ongoing funding for the existing capabilities that support this broad platform is essential to ensure Australia maintains its position as a leader in the integration of biological platforms globally.

#### ***Bioinformatics and Biostatistics***

Biomolecular science has become inextricably linked to informatics and eResearch infrastructure. Sophisticated bioinformatics and biostatistics tools and expertise are required to support experimental planning and quality control, storage, data curation, integration, visualisation and ultimately mapping to a biological context. In the next decade it will be crucial to ensure bioinformaticians, biostatisticians and computational scientists are increasingly embedded within biological laboratories rather than hosted in separate centres.

There is an underpinning bioinformatics and biostatistics requirement to support the full 'omics suite of research.

#### ***Genomics***

Genomic science has undergone amazing transformation in the last five years. Additional instrumentation to undertake DNA analyses (Sanger sequencing, short and long read shotgun

sequencing, single molecule sequencing) and associated robotics capability is required. Furthermore, RNA analyses using microarray and cDNA libraries remain essential tools for biological analyses.

### ***Proteomics***

Protein science requires additional capacity and capability in mass spectrometry, particularly leading edge instrumentation with high duty cycles, higher sensitivity and resolution. In addition, there is also a requirement for greater capacity for amino acid analysis and N-terminal protein sequencing. Monoclonal antibody development and production is a growth area and requires increased capacity, principally through automation.

### ***Metabolomics***

Mass spectrometry along with gas and liquid chromatography are essential requirements for metabolomics research. Nuclear Magnetic Resonance (NMR) spectroscopy has growing value in molecular identification and structural elucidation. The development of molecular libraries is also necessary and will allow for the continued standardisation of metabolomics research.

### ***Plant Phenomics***

Continued investment is required to develop novel imaging technologies to complement existing tools, particularly image analysis software, 3D modelling capacity and database management, is required. In addition, improved ICT infrastructure for accessing, interrogating and sharing large phenomics datasets and to integrate plant phenomics data with high throughput gene sequencing is needed.

### ***Mouse Phenomics***

It is desirable to integrate the current mouse exome analysis capability with other phenomics capabilities and with translational medicine. Parallel efforts in mouse and human exome sequencing and phenomics capabilities should be initiated and support is required to establish framework collections and mouse model capabilities including repositories.

Additional investment is required for exome sequencing programmes in mouse models and alignment of these efforts around key research strengths in Australia (such as cancer, malaria and immunological research). Further investment in large scale phenotyping as well as integrated phenomics specific data capture, storage and access to DNA and phenotyping data sets is necessary. This should be undertaken in conjunction with major overseas consortia to ensure open access to major international collections.

### ***Other requirements***

Australia's ability to participate in the international arena and collaborate with the world's leading scientists is enhanced by ongoing membership of large international consortia as well as the development of partner laboratories or mirror facilities. Continuing investment in such initiatives is a priority.

The data generated across the 'omics suite requires significant database development and analytical software for interpretation, management, storage and processing.

Access to multimodal imaging technologies, such as molecular, cellular and whole animal imaging (including: NMR spectroscopy, synchrotron science and microscopy) is an underpinning requirement. Additional requirements include high-throughput chemical screening, protein production, as well as facilities to hold small and large experimental animals.

It will be important to support the integration of emerging technologies and diagnostics with commercially available tools, in particular new measurement paradigms developed outside of the biological sciences community.

The development of integrated research facilities that can simulate the clinical setting would support Australia's position internationally. Such a facility would require infrastructure to support small and large animal and human research with ready access to imaging technology, 'omics suite sequencing and bioinformatics platforms<sup>30</sup>. However, this is likely to be Landmark infrastructure and as such would fall outside the scope of this Roadmap.

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<sup>30</sup> An example is outlined by the Division for Clinical Research Resources: Guidelines for General Clinical Research Centers Program (M01) National Center for Research Resources, National Institutes of Health, Department of Health and Human Services, October 2005.

# Biological Collections and Biobanking



## **Description**

The purpose of biological collections is to collect, document and store, in readily retrievable form, samples of species of flora and fauna in a secure and accessible form. Biological collections are physical databases that support the understanding of the variability of biodiversity. Biological collections also include the storage and characterisation of germplasm which will support the preservation of natural and crop biodiversity.

Biobanking is an innovative approach to the conservation and sustainable utilisation of diverse genetic resources. It allows researchers to draw more robust conclusions regarding the effectiveness of medical therapies. It offers unique opportunities to research, assess and document global genetic diversity and define new research directions. Biobanking involves sophisticated systems for the management of tailored facilities that collect, store and distribute biological resources as well as associated information stored for one or more purposes.

## **Strategic Impact**

The information derived from biological collections and biobanks has important applications in preventative medicine, plant phenomics, animal models and sequencing and conservation of unique biodiversity.

Australia possesses sizable cohorts of clinical patients, collections of agriculturally and environmentally significant plants and insects, and unique flora and fauna that represent tremendous opportunities for discovery and provide underpinning information for a myriad of research challenges. Such collections will provide Australian researchers with infrastructure essential to advances in biomedical and environmental research.

Biological collections and biobanks will offer toolsets for accelerated knowledge and scientific discovery. They provide information on Australia's terrestrial and marine biodiversity that is essential for natural resources management, understanding impacts on Australia's biodiversity and mapping threats from invasive species.

Development of nationally coordinated biobanking infrastructure to facilitate access to biospecimens (and associated data, such as clinical data for health biobanking) will result in improved outcomes for patients and the production of high-quality, credible research. Such research has a clear link to the development of improved diagnostic pathways and more targeted and effective therapies for patients. This in turn produces economic efficiencies by providing avenues for more cost-effective allocation of health funding to the most appropriate therapy for each patient.

Access to health biobanks has the potential to improve research outcomes relating to the prevention, diagnosis and treatment of a wide range of serious and life-threatening illnesses including; cancer, heart diseases, diabetes, inflammatory bowel disease, arthritis and dementias.

The benefits of a nationally coordinated approach to biospecimen collection and storage include access to larger sample sizes for research, increased awareness of specimen availability and standardised quality and consistency of sample collection and preservation. This will lead to economies of scale, which will facilitate the critical long-term follow up of samples.

## ***Challenges and Assumptions***

Biological studies require appropriate collection and storage of fixed or frozen tissue samples as well as the mechanisms to facilitate timely access to these biospecimens for analysis. This relies on networked, easily accessible biological collections and biobanks, which will provide repositories for a diverse range of biological samples.

Australia currently has a large array of relatively small collections of biosamples housed primarily within individual research laboratories. The bulk of these collections are comprised of research specific samples. Australia currently lacks national coordination of malignant and benign tissue, blood or other bodily fluid samples for health research and plant, animal, soil, water and atmospheric samples for ecological and biodiversity research.

A challenge will be to link the data from biological collections with broader environmental observation datasets. Integration of these datasets is fundamental to Australia's capacity to manage its biodiversity in an intelligent and sustainable way.

A major challenge for this capability is the secure storage and researcher access to individual health records and biological tissue samples. However, a body of work is being undertaken by government agencies to address these issues, which is discussed further in the Population Health Platforms capability. Strong integrated management systems for archived collections are an underlying requirement across the research sector, incorporating adaptive data models and processes for the management of intellectual property, policy issues, services and maintenance.

This capability is inextricably linked with the functions of the Integrated Biological Discovery capability because of the requirement for genotype and phenotype analysis of the samples, and the use of bioinformatics and biostatistics to support understanding at a system level. In addition, the imaging processes provided through the Characterisation capability are essential.

## ***Specific Requirements***

Nationally coordinated and networked Biological Collections and Biobanking facilities are required.

The complex nature of developing such facilities will require nationally agreed protocols and standards for the collection, storage and access to the samples.

Secure storage under controlled temperatures and humidity, with backup systems are necessary. Bar-coded archiving of samples accessible via robotic retrieval systems is also desirable.

Laboratory information management systems including data dictionaries, data integration and linkage are also essential to maximising the benefits of these collections.

# Integrated Biosecurity



## **Description**

The risk to Australia from new and emerging pests and diseases is growing with greater international mobility, more open trade and climate change. While biosecurity events have economic and market access implications for Australia, they also have major impact on environmental, animal and human health, along with agricultural productivity and food security.

The biosecurity research domain is evolving to better manage these risks. The current model has mainly dealt separately with plant, animal and human disease and pest incursions. This is beginning to be considered more holistically as elements of an integrated approach. This evolving model increasingly is being termed 'One Health', and is expected to form the basis for Australia's biosecurity research activities in the future.

This perspective transcends traditional detection and eradication of animal, plant or human pests and diseases to consider how location, movement and interaction of populations, modified by climate change and/or environmental degradation, will impact on potential biosecurity events. With this contemporary view of biosecurity comes a need for access to and integration of many levels of data within an integrated secure data sharing capability. This capability is required to facilitate interaction between various disciplines and research areas.

## **Strategic Impact**

Geographically and genetically separate from the rest of the world, with climatic variations from tropical to alpine, temperate grasslands to deserts, Australia is susceptible to emergence and incursion of biosecurity threats from both endemic and external sources. The movement of biosecurity threats from traditional geographical regions and host vectors to new and unknown locales requires a holistic and integrated biosecurity research effort to effectively manage these threats.

The 'One Health' model recognises the interaction of biosecurity research with other research domains. Demand for increased production of specific food groups creates new challenges in maintaining food security, and in turn creates new risks for the transmission of diseases. The continued rise of new human diseases from zoonotic sources (currently 70 percent of all new infectious diseases) requires closer integration of biosecurity and human health resources to correctly identify and treat new outbreaks. All of these factors represent a significant and increasing threat to public health, veterinary health, tourism, trade and the economy.

## **Challenges and Assumptions**

Developing an Integrated Biosecurity capability will require the closer alignment and integration of researchers, research infrastructure and datasets across the broad domain areas encompassed.

While the range of domains in biosecurity research is considerable, there are many similarities in their needs. Providing appropriate infrastructure and access arrangements, linked to collaboration and data sharing tools, will best ensure the development of multidisciplinary groups spanning environmental, animal, plant and human health, and food security research areas. A challenge is to ensure that any future investment builds on the current direction of more open access and the breaking down of silos between disciplines and facilities.

An effective capability in this area would interact and link with other capabilities including Integrated Biological Discovery, Biological Collections and Biobanking, Characterisation and the environmental capabilities.

### ***Specific Requirements***

Various national and state agencies have developed significant and specialised biosecure research laboratories that could be integrated into this capability. Analysis of gaps and duplication within the current research laboratory network is core to the next steps in investment, prior to the integration of facilities. Links to environmental, food security, and human, animal and plant health research capabilities, both within and outside biosecure facilities will enable researchers to create and draw upon resources of all associated fields.

These specialised laboratories need specific equipment and expertise to be available within highly biosecure research environments, particularly Physical Containment 3 and Physical Containment 4 (PC4). There needs to be enhanced ability to conduct sophisticated analysis and scanning at both the macro- and micro-biological level, including characterisation, biological platforms and flow cytometry. Support for the ability to breed and study both common and uncommon disease vectors on both large and small scales in a biosecure environment and facilities to undertake research into disease management and food security requirements in aquazoology should also be considered.

Key to the Integrated Biosecurity capability is the ability to draw upon data and resources from a wide variety of sources and domain areas, from biosecure and non-biosecure areas, in multiple jurisdictions and the utilisation of equipment remotely. The investments to date provide data integration, linkage and collaboration capability for the biosecurity community and should be built upon. However, there is a need to ensure that the data linkage research infrastructure meets the needs of biosecurity researchers as a research network, rather than a network with an operations focus.

An important driver is to increase the reach beyond national security-focused researchers, and to integrate interaction between biosecurity and other environmental and human health datasets and collections.

Specialised equipment in physical containment, especially PC4 facilities, will enable new research and reduce experiment time. Remote collaboration and data sharing technologies are required to enable improved collaboration between researchers in different physical locations, including biosecure and non-biosecure areas, and across disciplines.

# Population Health Research Platforms



## **Description**

The capacity for researchers to access an integrated, national resource of population-based health data will contribute to identifying the causes of disease, developing new diagnostic, preventative and therapeutic interventions and evaluating and improving clinical practice, health services and health policies. The ability to link data and develop models that cross organisations, sectors and disciplines will make a powerful contribution to identifying emerging issues, such as epidemics or adverse drug reactions, and understanding the interplay of social, environmental and biological factors in causing and controlling major common health problems.

This platform is required to link Australia's collections of population-based health data and make them available to researchers through secure privacy-preserving mechanisms. The data will comprise key administrative health datasets, data from cohort studies and clinical trials, and genetic and physiological information derived from biospecimens. This capability will provide Australian researchers access to linkable, de-identified data from a wide range of health datasets, across jurisdictions and sectors.

## **Strategic Impact**

Health services in Australia, and internationally, face huge pressures relating to population growth and ageing, increasing prevalence of common chronic diseases and the costs of technological developments in health care. This creates an imperative for research to identify effective preventive interventions, and to inform the allocation of health resources to achieve the best health and societal outcomes.

Australia is well placed to emerge as an international leader in research using linked administrative data. The scope and population coverage of health data infrastructure in Australia supports research to explore health differential and inequalities, geographic and spatial aspects of health, and the effectiveness of health services. There is tremendous potential to expand existing linkages to incorporate a wider range of administrative data, such as from community-based and residential aged care services, education, child protection, crime and forensics.

Australia has a collection of high-quality population-based cohort studies. It is likely these will continue to underpin a wide range of research, particularly if they are linked with administrative data and expanded to include biodata. This will enable the translation of advances in molecular biology and other fundamental sciences to solutions at the population level.

Australia also has a wide range of routine registers relating to disease, treatments and devices, which supports the clinical trials industry. Data from these sources can be linked with administrative data for long-term follow-up and ongoing monitoring of adverse outcomes. This research has the potential to inform action to reduce the use of harmful or ineffective treatments, and to redirect resources towards cost-effective options.

A world-leading, comprehensive population health research platform will support a wide community of researchers from multiple disciplines, including the social sciences, public health, health services research, clinical research and biomedical research.

## ***Challenges and Assumptions***

Research that uses health data relating to individuals presents ethical and privacy challenges. Conversely, technological advances are delivering new tools to protect privacy and improve data security. A mutually satisfactory balance in regards to ethical and privacy challenges is likely to be achieved by a combination of policy-centric and technology-centric measures.

Existing cohort studies, registers and data from clinical trials are managed by diverse public and private sector entities using a wide variety of access models. Currently, many cohort studies and registers rely on short-term project funding to support their maintenance, follow-up and tracking activities, challenging their long-term sustainability.

Research using large-scale population data is highly dependent upon capabilities in biostatistics and bioinformatics and this capability will therefore need to interact and link with the Integrated Biological Discovery and Biological Collections and Biobanking capabilities.

## ***Specific Requirements***

There is a requirement to expand Australian capabilities for health data linkage and for a platform which will also provide new infrastructure for the efficient acquisition, management, analysis and governance of health data.

It is envisaged this capability will build upon the infrastructure already developed. Incorporation of a wider range of data will involve extensive stakeholder liaison and policy development, as well as investment in further development of systems for the secure storage, management, transfer and archiving of data, and for performing data linkage.

The Australian Government has signalled that its linked data (including key Medicare Benefits Schedule, Pharmaceutical Benefits Scheme and aged care data) will generally only be available to researchers through on-site data laboratories or secure remote access facilities. A cross-portfolio committee has been established to develop systems under which Australian Government data can be made available. The committee aims to create a consistent and unified approach to facilitate linkage of social, economic and environmental data for statistical and research purposes.

Partitioned workspaces or enclaves for hosted research studies can meet the need for secure access but significant additional investment will be required to meet growing demands from a broader group of researchers.

Incorporation of data from cohort studies, registers and clinical trials into the platform will require the development of new mechanisms to govern and manage these data sets as an open-access resource while still maintaining appropriate arrangements with regard to intellectual property.

Infrastructure to support the efficient ongoing operation of cohort studies and registers will be required if they are to form a key part of this platform. This could include shared infrastructure for cohort recruitment, maintenance and tracking as well as for the storage, management and linkage of data.

The platform will also need to be supported by specific eResearch infrastructure, including a range of accessible tools and resources for data management and analysis.

# Translating Health Research



## **Description**

Bridging the gap between the discoveries by researchers and treatment received by patients not only has an effect on the quality of patient care and health outcomes but also impacts on the nation's economy. To capture the full value of Australia's public and private investment in health research, pre-clinical capabilities are required.

Translating health discovery into improved health outcomes requires an underpinning set of research infrastructure that allows individual discoveries to be progressed.

Translating health research is the process which leads from basic medical research to sustainable solutions for public health problems. It aims to improve the health and longevity of the public and depends on developing links between basic scientific discoveries and clinical investigation, informed by evidence from the social sciences.

This capability will provide effective and efficient pathways for potential therapeutics and medical devices to move from the discovery stage into, and through, preclinical testing, clinical trial design and clinical trials, in order to meet the various requirements of regulators for release. Supporting the translation of research findings into sustainable improvements in clinical and health outcomes is required for greatest research outcomes.

## **Strategic Impact**

Breakthroughs in therapeutic and other medical treatments have the potential to improve the quality of life of Australians. Australia has significant strength in health and medical research but needs additional capacity to support the effective and efficient transition of research from the laboratory. Platforms for translating health research will provide an infrastructure service to facilitate this, ultimately leading to faster, more cost effective drug therapy development and implementation.

Increasing the rate of development and implementation of effective new diagnostic tests, devices, treatments and preventive interventions through more efficient translational pathways and services will result in: improved population health in general; economic savings through more efficient processes; decreased cost of drugs; better and faster clinical trials; improved translational medicinal chemistry; a reduced health care burden at the national level as well as on individual institutions; industry benefits; and improved international engagement and collaboration.

Major patient cohorts and clinical collections will be able to be analysed nationally in a discovery phase utilising genomics to uncover new biological pathways that can better inform drug development and pharmaceutical use. Individualised treatments will be the next goal with the identification of specific biomarkers that can be developed into diagnostic assays.

The development of new medical and preventative treatments has export potential for Australia, as well as the ability to create jobs through local manufacturing industries. Investment in this capability will allow Australia's health system to remain internationally competitive and ensure Australian's have access to health outcomes commensurate with other developed countries.

## ***Challenges and Assumptions***

This capability area intersects with most areas of the health sector. The wide scope of this sector, number of change initiatives underway and the breadth of research infrastructure requirements make the process of identifying and prioritising research infrastructure gaps in this capability challenging.

Specific to this area are also the challenges of sourcing funding for pilot studies, meeting ethics approval requirements, recruiting of clinical trial participants, and managing interactions between clinical researchers and industry, all of which are in addition to infrastructure requirements.

There are substantial overheads involved in translational activities, but this is a particular issue for those that have public good rather than commercial outcomes.

The success of this capability depends upon interaction with the Integrated Biological Discovery, Characterisation, Population Health Research Platforms and Biological Collections and Biobanking capabilities.

## ***Specific Requirements***

Current investment represents the first steps in supporting researchers to bridge the translational gap from basic to potential therapeutic application.

Infrastructure is now required to support research into medical devices, drug delivery systems, diagnostics or surgical devices.

In order to create a national, integrated, systemic approach to meet the needs of therapeutics researchers there needs to be an enhanced infrastructure capacity for clinical trials, as well as associated collaborative activities and information sharing tools.

Continued support is needed for existing infrastructure for large-scale mammalian and non-mammalian cell-based manufacture of recombinant proteins as potential therapeutics. This includes 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 include support for the growth of stem cells, mature cells, cell lines and animal cells with links to bone marrow and cord blood facilities.

Additionally, a national small molecule repository and a national screening network to identify small molecule drug candidates is necessary. Enhanced and more integrated primary and secondary drug screening capability is also required to enable deeper and more insightful analysis of drug action.

Ongoing support for the manufacturing of pre-commercial amounts of new therapeutic biological products with the appropriate support structures to foster Phase I and Phase II clinical trial activity is essential. An integrated network of preclinical testing facilities is needed, including absorption, distribution, metabolism, excretion and toxicology, animal disease models and biomarkers testing.

Support for a national small and large animal preclinical trials and testing facility with an increased capacity in high quality animal pathology and phenotyping should be considered.

Cross disciplinary bioinformatics is required to address the convergence of high-end computing, computational biology and molecular sciences, which has implications for translational research.

# Astronomy and Space Science



## ***Description***

Astronomy research in Australia and internationally will continue to be focussed on understanding the fundamental physics of the Universe. Such knowledge will be gained by answering key questions on the origins and evolution of galaxies, stars and planets; probing the physics of extreme environments; gaining deep understanding of the fundamental forces and forms of matter and energy that make up the universe; and studying the building blocks of life.

To address these questions, fainter signals and more distant objects must be studied across increasingly large parts of the electromagnetic spectrum, at ever higher resolution. Astronomers require access to state-of-the-art observatories and technology that span the spectrum from radio waves to gamma rays, and employ high-energy particle detectors, space craft and advanced instruments which probe a wide variety of astrophysical phenomena.

Space science complements astronomy and earth sciences by addressing the properties, dynamics and evolution of the solar system and humankind's place in it, from the sun to the earth's ozone layer and into the local interstellar medium. Space science provides data returned by Earth Observation Systems (EOS) and Global Navigation Satellite Systems (GNSS) that is utilised by a wide range of strategically, economically and socially important disciplines, including geology, geophysics, environmental and climate science, and national security.

## ***Strategic impact***

Astronomy and space science are enabling sciences in which Australia demonstrates high research performance, discovery and impact. This success results in part from previous significant investments in infrastructure and expertise.

The Australian research sector, economy and society derive valuable benefits from astronomy and space science. Observations of the earth from space contribute to predicting global weather, studying climate, managing water availability, understanding agricultural and urban impacts, mitigating natural disasters, monitoring coasts and oceans, and mineral exploration.

Data and services from space-based platforms and ground-based observatories are building our understanding of the dynamics of the sun's interactions with communications systems, and the geospatial and geochemical structure of the earth.

Astronomy and space science operate in regimes that push the boundaries of technology. Investment in new enabling infrastructure for these disciplines will continue to stimulate industry.

The Square Kilometre Array (SKA) has the potential to transform data usage and management; to push the boundaries of high performance computing; and to stimulate new methodologies for data reduction and mining to extract meaningful information from huge data sets. Dual use of SKA network infrastructure may support the deployment of national sensor networks for atmospheric, ionospheric, seismic, climatological, geophysical and land use research.

New astrophotonic devices, radio instrumentation and image processing methods developed for astronomy can be adapted to applications ranging from new medical imaging systems to laser telescopes that detect orbiting space debris that may damage valuable satellites. Niche industry capabilities stimulated by investments in research infrastructure for the development and testing of

astronomical and space instrumentation are expected to extend to other research sectors, ranging from telecommunications and aerospace to medical science, environmental science and national security.

Support for the development of domestic space-borne instrumentation, data acquisition systems and augmentation of ground-based support infrastructure for EOS and GNSS will allow Australia to assure ongoing access to critical space-enabled services. This support will enhance Australia's standing as a contributing and influential partner in international space science consortia.

### ***Challenges and assumptions***

Progress in astronomy is now characterised by larger, more complex, more expensive and increasingly international observatories. In contrast to previous nationally-owned observatories, Australia will, in future, generally become a shareholder in the most advanced international facilities.

An important direction in international astronomy is toward large optical and radio surveys of the whole sky. Australia is well-positioned to conduct and contribute to these, using existing wide-field instruments such as the Anglo-Australian Telescope (AAT), the Australian National University's SkyMapper optical telescope and the new Australia Square Kilometre Array Pathfinder (ASKAP) radio telescope.

While there have been substantial benefits from major capital investments in Australian astronomy in the last five years, a key challenge in the coming five years is to continue the operations of these facilities. Research infrastructure support must be flexible to allow for the mix of investment in infrastructure and expertise to respond to changing needs. This will require the astronomy community to prioritise and trade-off between existing and new facilities.

Effective infrastructure investment in the global research environment requires a long-term strategic approach, ideally providing access across a wide range of capabilities. One potential approach, embodied by the European Southern Observatory, is to team with countries that share Australia's envisaged research needs, to plan, manage and fund facilities. The transition to such a model may require a significant one-off capital outlay, with the potential long-term dividend being a more efficient allocation of resources.

Australian scientists are active in international collaborations to develop technologies for gravitational wave detection, to open a new window for astronomy. However, the establishment of a gravitational wave observatory in Australia is not a research infrastructure priority for Australia's astronomy sector, as it will remain in the realm of experimental physics until gravity waves are routinely detected. In addition, the required level of national investment to establish a gravitational wave observatory puts it in the category of Landmark infrastructure, beyond the scope of this Roadmap.

An enhanced space capability will address an important layer in Australia's national research infrastructure, between earth science and astronomy, by building upon existing investments in these fields. It is important that any investment in research infrastructure to support space science takes into account the broader space related activities of the Australian Government<sup>31</sup>.

Australia will continue to rely on data received from international space systems and so must ensure best use of geographic and other comparative advantages as a location for ground station facilities and ground-based calibration and verification, and build on the respect it has achieved through international scientific and technical collaboration.

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<sup>31</sup> <http://www.space.gov.au/Pages/default.aspx>

Infrastructure investments that support international collaborations in EOS, GNSS and space technology, including space-borne and ground based instrumentation, launch vehicle and satellite propulsion systems and new GNSS receiver and software systems, will allow Australia's research sector to continue to contribute to, influence the operations of, and benefit from ongoing access to international space systems. There is no strong case to support Australia developing an indigenous launch capability.

A wide range of capabilities throughout this roadmap will benefit from enhanced space science capacity, in particular the environmental, Integrated Biosecurity and Biological Collections and Biobanking capabilities. This capability is also reliant on continued development of advanced sensors, sensor networks and instrumentation.

### ***Specific requirements***

To maximise the benefits of the science of space and science from space, Australia's astronomy and space science community requires a coherent and complementary mix of national observatories, access to major international facilities and their scientific data, technical development facilities, advanced instrumentation and a robust, tailored eResearch fabric to manage and analyse the scientific data.

The *Mid-Term Review of the Australian Astronomy Decadal Plan 2006-2015*<sup>32</sup> of the National Committee for Astronomy identifies several priorities and should form the starting point when considering the research infrastructure requirements for astronomy. The priorities at the national scale include:

- securing long term access to forefront optical facilities
- continuing support for the Australian Astronomical Observatory and the AAT
- continuing involvement in the Giant Magellan Telescope (GMT)
- developing an astronomical fabric of hardware and software to exploit the coming data deluge from current and upcoming telescopes and instruments.

Australia has a strong track-record of innovation and home-grown expertise in the field of astronomical instrumentation that complements and supports investments in major observatories. Building upon this, astronomy, space science and the high-technology research sector all stand to benefit from targeted investments in specialised facilities to enable the design, fabrication and testing of advanced instrumentation for telescopes, remote sensing and space science platforms.

Space science research will also benefit from access to individual and networked ground-based sensors, radars and instruments such as EOS and GNSS receivers, continuously operating reference stations, software and data sets and a variety of small near-earth satellites.

Space scientists and researchers who rely upon earth observation and position, navigation and timing would benefit greatly from integration of EOS and GNSS applications and eResearch infrastructure. This would enable close-to-real-time assimilation of multiple space data streams into theoretical models and managed access to suitable radiofrequency spectrum.

Australia's international participation in space science would be advanced by developing space technology including new radar and integrated photonics instruments as well as HPC facilities and software for space technology simulation. The sector also requires laboratory test and development facilities, for example, to progress the development of satellite instrumentation, plasma thrusters and hypersonics, in particular scramjets and high thermal-load materials.

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<sup>32</sup> <http://www.science.org.au/natcoms/nc-astronomy/documents/MidTermReviewPlan.pdf>

The space science sector also requires government support in the national coordination of civil space use, and for participation in international regulatory frameworks, treaties and protocols that support Australia's use of space. Australia's growing dependence on major international astronomical facilities and space systems will require new government-to-government arrangements, as well as programs and services to enable Australia's institutions and companies to contribute materially to international infrastructure.

# Sustainable Energy



## **Description**

Australia's prosperity relies on secure, affordable and sustainable energy. The Australian Government has legislated for 20 percent of electricity to come from renewable energy by 2020 and a reduction in our greenhouse emissions by 60 percent over the next 40 years (Department of Climate Change and Energy Efficiency, 2010)<sup>33</sup>. To achieve these goals, the current investments in maturing existing technologies need to be complemented by infrastructure to enable research into next generation or disruptive technologies.

A coherent energy system will require a mix of technologies. This 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 has access to a number of significant sustainable energy sources that are beginning to make a contribution to base-load generation including solar, wind, geothermal and ocean power. Next generation biofuels, battery and fuel cell technologies are some of the energy options for transport and field use under development. A truly long-term solution for large-scale, non-polluting energy supply may eventually come from nuclear fusion. The future energy landscape will undoubtedly be more diverse than the present one.

## **Strategic Impact**

Providing secure, affordable and sustainable energy is vital to maintaining Australia's prosperity. Demand for Australia's energy – both domestically and for export – is growing strongly. We must ensure that our energy resources are developed efficiently and sustainably to optimise the overall benefit for the Australian community.

Continued security of, and access to, a competitively priced energy supply for households and industry is a critical priority. Alongside this, Australia needs to continue the transition to a low emissions and environmentally sustainable economy. This will require the development and deployment of new and cleaner low emission technologies supported through actions such as the introduction of a price on carbon.

Advances in energy systems engineering fundamentally rely on the discovery of advanced materials, their fabrication into components and deployment in engineered systems. The potential for disruptive technologies in energy systems is widespread, affecting sectors such as energy generation, hydrocarbon exploration and exploitation, vehicle technology and electrical power networks.

To capture a portion of the high-value growth markets arising from such developments, Australia will require infrastructure to support research along the value chain from materials design to component prototyping and testing.

Advancing the understanding of Australia's energy system and the potential impact of emerging technologies on the production, distribution and consumption of energy will be crucial to informing policy that drives appropriate infrastructure and other investment choices.

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<sup>33</sup> <http://www.climatechange.gov.au>

## **Challenges and Assumptions**

In recent years, a number of initiatives have begun to address energy and emission issues relevant to a sustainable energy landscape, and a major challenge will be to ensure any investment in research infrastructure complements these various research efforts and provides a basis for further fundamental research. Some examples include:

- The *Carbon Capture and Storage Flagships Program*<sup>34</sup> which supports the construction and demonstration of large scale integrated carbon capture and storage projects in Australia;
- The *Solar Flagships Program*<sup>35</sup> which supports the construction and demonstration of large scale, grid connected solar power stations in Australia;
- The *Australian Solar Institute*<sup>36</sup>, established by the Australian Government to support solar thermal and solar photovoltaic research and development;
- The *Australian Centre for Renewable Energy*<sup>37</sup>, which promotes the development, commercialisation and deployment of renewable technologies through a commercial investment approach;
- The *Smart Grid, Smart City*<sup>38</sup> project which will demonstrate a range of smart grid technologies and applications, providing extensive data about the potential benefits;
- CSIRO's *Energy Transformed Flagship*<sup>39</sup>, which aims to lower greenhouse gas emissions by providing sustainable, efficient, cost effective energy solutions for electricity supply and transport; and
- The *Australian Biofuels Research Institute*<sup>40</sup>, which aims to increase Australia's energy security and diversify sources of liquid fuel supply through the next-generation biofuels.

The Energy White Paper process being undertaken by the Department of Resources, Energy and Tourism, expected to be finalised in 2012, should also be referenced when considering the infrastructure requirements for energy research.

The existing investments and any future enhancements in the Characterisation and Fabrication capabilities should provide significant fundamental support for energy research, particularly in the advanced materials area. In addition, the subsurface observation capacity proposed in the Solid Earth capability area has clear applicability to research into carbon capture and storage and geothermal energy.

## **Specific Requirements**

Given the broad nature and scale of energy-related research and development, infrastructure to support research into specific processes and related activities 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 approach will required to develop a coordinated whole-of-government understanding of 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, existing and planned investments and initiatives, areas of research strength, and

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<sup>34</sup> <http://www.ret.gov.au/energy/clean/cei/ccsfp/Pages/default.aspx>

<sup>35</sup> <http://www.ret.gov.au/energy/clean/cei/sfp/Pages/sfp.aspx>

<sup>36</sup> <http://www.australiansolarinstitute.com.au>

<sup>37</sup> <http://www.ret.gov.au/energy/clean/cei/acre/Pages/default.aspx>

<sup>38</sup> <http://www.smartgridaustralia.com.au>

<sup>39</sup> <http://www.csiro.au/org/EnergyTransformedFlagship.html>

<sup>40</sup> <http://minister.ret.gov.au/mediacentre/mediareleases/pages/budgetaustralianbiofuelsresearchinstitute.aspx>

the international energy research environment.

The focus of investment in national, collaborative research infrastructure may be best targeted at early stage, basic research into energy processes. This would provide a foundation to support new or disruptive technologies and foster continuing basic research and innovation across the broad range of energy sources and systems.

In addition, consideration could be given to continued support for research infrastructure related to fusion power to facilitate linkages with international activities such as the *International Thermonuclear Experimental Reactor (ITER)*<sup>41</sup> project.

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<sup>41</sup> <http://www.iter.org>

# Cyber Security



## **Description**

The Australian community and economy increasingly rely on electronic systems for all aspects of daily life. Improvements in the handling, retrieval and communication of information have delivered significant economic and social benefits to the nation and the impact of these trends will accelerate into the future.

However, interconnected electronic systems have opened new areas for exploitation by criminals, terrorists and other disruptive elements. Australia needs research infrastructure in order to develop the capability to research ways to predict, identify, mitigate and prevent cyber security breaches before they occur and to rapidly analyse and resolve breaches that take place.

## **Strategic Impact**

Advances in the technologies we use, and the reasons we use them, are accompanied by developments in the number and type of cyber threats faced. A safer and more secure internet will be achieved through focusing on the technical and procedural challenges associated with securing electronic communications infrastructure against cyber attack and resultant cyber crime.

Organisations, institutions and critical infrastructure can be made more secure by investigating information security challenges and techniques. This will assist in protecting the finance sector and critical cyber and process control systems, such as those which regulate energy and water supplies.

The detection and reporting of inappropriate and illegal use of ICT systems is essential to analyse what attackers do and why and to develop advice for governments and organisations on policing, policy and new legislation.

The analysis of emerging and disruptive technology trends and their impact on future cyber security needs is also necessary. These technologies include quantum computing and quantum encryption, future evolution of cloud computing and exascale computational capabilities.

## **Challenges and assumptions**

Cyber security research is confronted by major challenges in building cooperation across multiple jurisdictions involved in this area. Security research intrinsically involves agencies that normally tightly control access to their facilities, programs and researchers.

The inclusion of this capability in the Roadmap may help to improve the linkages between organisations and researchers, so that a community consensus on priorities for cyber security research infrastructure can be formed. However, due to the nature of their work, some researchers in this field will inevitably be unable to share information on the nature of their research and facilities available to them, making such a prioritisation a challenge.

The underlying research and research infrastructure needs of a Cyber Security capability will have to align with existing interests and activities in the realm of cyber security, primarily from an operations and prevention point of view.

As with several other capabilities, there are also challenges in defining infrastructure that is primarily needed for research, rather than driven by operational interests.

Additionally, consideration must be made of privacy and security principles, as these can at times affect the ability of researchers to openly their work and collaborate in the use and operation of infrastructure.

Effective cyber security systems are essential for ensuring the integrity of Australia's research efforts.

### ***Specific Requirements***

Key research infrastructure to draw together and support the research community will be required. Ready access to a variety of national and international databases for which new security processes, storage infrastructure and stringent audit capabilities can be tested, and methodologies and interruptive systems developed is also necessary.

The development of advanced tools and processes to monitor, collect and visualise large volumes of digital evidence is required.

In addition, the following categories of infrastructure to support cyber security research could be considered, although they may fall into the Landmark category due to the size of the investment required:

- test beds and ranges, in which new devices might be tested in isolation and then within the context of networks of other devices with the aim of detecting and understanding vulnerabilities
- immersive modelling and simulation centres in which human behaviour as individuals and groups can be facilitated and studied
- advances in communications, especially in access to exceptionally fast and wide bandwidths, will be essential for sophisticated national and international research and experimentation.

## Cultures and Communities



### **Description**

Australia's humanities, arts and social science researchers are recognised internationally for delivering solutions to challenging questions facing society and for bringing their expertise to bear on complex issues, such as in health, the environment, social cohesion and security. Their work encompasses law, society, education, identity, economics, business, governance, history, culture, language and creativity. Their fields link universities, government agencies, collecting institutions and creative industries.

The Cultures and Communities capability is required to make both old and new data discoverable and reusable and to extract greater value from existing collections, as varied as statistical data, manuscripts, documents, artefacts and audio-visual recordings. These materials reside in a diverse array of repositories, many of which are unconnected.

Interoperable, standardised databases and networks will enable manipulation and comparison of these variable research materials. Dedicated tools will enable researchers to assemble, combine and analyse data sets at a scale not previously possible, to produce holistic answers to complex questions and link researchers across virtual communities nationally and internationally.

### **Strategic impact**

The implementation of this capability will have major, long term ramifications. The results of humanities, arts and social science research are of immediate interest to the general population, policy-makers and the greater research community.

The objectives and impact of this research will be accelerated and more widely distributed through streamlining access to Australia's data holdings, enabling discovery of previously hidden data, stimulating connections and synergies and catalysing innovative research. Providing easy accessibility to data and powerful analysis methods will enable effective data-mining and re-use, maximising the return on previous research investment.

Analysis of immense, complex and diverse data sets through new tools will reveal implications and insights not possible in the past. Tools which permit efficient collation, manipulation and recombination of diverse data sources will enable new research fields to be pioneered.

Policy-makers and the broader community will benefit greatly from the results of research enabled by this capability. Combined with the accessibility afforded by modern digital infrastructure, geographically dispersed Australians will be able to access information relevant to their cultures and histories. The interactive nature of the capability will allow individuals and groups to contribute to the data as well as to use it.

### **Challenges and assumptions**

This capability area will provide fundamental and pervasive support for the majority of the capability areas articulated in the Roadmap. For instance, the integration of data from this capability with environmental data will increase our understanding of human impacts on our environment.

As well as contributing to research undertaken in other capability areas, this capability depends significantly on the eResearch and Digitisation Infrastructure capabilities. The implementation of the

Digitisation Infrastructure capability will unlock research data held across Australia, the legacy of massive research investment in the past. Once digitised, the uses for data are almost limitless when made available through the research infrastructure of the Cultures and Communities capability.

Much of the Cultures and Communities capability will be based on eResearch tools and techniques. However, while the cultures and communities research sector has embraced eResearch knowledge, skill levels vary widely across the sector, and skills and training need to be addressed by researchers and research organisations.

The diversity of the sector and the disparity of data formats in existing collections, as well as inconsistent metadata, are challenges for this capability and one of the key rationales for its development.

Research data in the domain of cultures and communities may be sensitive from a cultural, individual or other perspective, and solutions to this challenge need to be integrated at a systems level. Access to the large amounts of data owned by individual institutions will require commitment by those institutions and the wider research community.

At a broader level, there is a challenge in ensuring researchers have access to resources to guide them in the best methods related to their fields – how to best capture and store the type of data used in their research area, the most appropriate repositories for their type of data and the techniques most appropriate for dealing with non-digital data.

The breadth of this capability and the diversity of its disciplines will make implementation a challenge. To ensure rational and effective investment, a high level of consultation across the nation and across diverse institutions will be required. The establishment of a body to oversee and guide the implementation and on-going development of the capability may need to be considered to ensure the greatest benefit for the sector.

### ***Specific requirements***

Purpose-built, easily accessible, interoperable and dedicated eResearch platforms will comprise networks of databases, spaces for collaboration, resources and tools, enabling access to and analysis of diverse datasets. Accessible from researchers' desktops, these platforms will link individuals and groups of researchers with virtual research communities nationally and internationally. Platforms may be formed around research themes which bring together tools and datasets which will bring the most benefit to the research community.

A variety of networking and access tools are required to facilitate use of the diverse data currently stored in repositories. Not only must current repositories be made accessible to researchers, services are required which enable the conversion of data, currently in a variety of formats, into forms which are useable by a variety of researchers. These access and format conversion tools will be at the heart of unlocking our current repositories of data.

Protocols must be established for future data sets which are Open Archival Information System<sup>42</sup> compliant. This will ensure that data is generated and made available in appropriate formats with proper metadata descriptions, is captured and managed to international standards, is curated efficiently and is discoverable and accessible.

The power of the capability can only be realised if disparate data sets can be connected, combined and analysed. To do this, tools are required which specifically address the needs of the sector to capture, analyse, visualise and interrogate the types of data of relevance to the sector – documents, audio-visual files, images and statistics.

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<sup>42</sup> <http://www.nla.gov.au>

The provision of virtual spaces for collaboration will be of particular importance in fostering effective use of these data resources and promoting interdisciplinary work.

**Illustrative example: A potential digital atlas of Australian people**

A digital atlas of Australian people would unite disparate social and cultural research data with collection information, within a broad geographic framework, and could be a powerful tool for researchers responding to questions of national urgency. It would provide a platform for collaboration, and enhanced access to a range of source material (collections) across a broad sweep of disciplines within the humanities and social sciences, while facilitating links to relevant research on the environment, population, or health. As an example, researchers investigating water flows and usage along the Murray Darling river system might enrich their environmental studies with research on the varied histories, economies or sociology of different areas, while accessing original source material from libraries, museums and archives. Communities could be directly involved in research projects and policy debate through interactive tools.

# Marine Environment



## **Description**

Australia is a marine nation, extending from the tropics through subtropical and temperate waters down to the Antarctic continent – and its future is linked to its oceans.

Planning for the future, whether for adaptation to climate change or the management of marine resources, requires access to the best possible ocean information. Sustained observations of the ocean are essential to deliver the knowledge needed to inform decisions made by government, industry and the community.

The Marine Environment capability will continue to require an integrated and coordinated approach to data collection, storage and management to enable modelling and interpretation to support a greater understanding of the marine environment, including coastal ecosystems and marine living resources.

## **Strategic Impact**

The scope of research in the marine environment is extensive. Australia needs to continue to capture the benefits of its growing marine capability, to expand its coverage and to sustain it in the long term. In addition, the maintenance of an ongoing, robust national framework for planning and coordination between marine science agencies and the wider marine community remains critically important.

Recently released national frameworks and plans for climate<sup>43</sup>, marine<sup>44</sup>, the Antarctic<sup>45</sup> and earth system science<sup>46</sup> provide important guidance and linkages for strategic marine research infrastructure investment.

Sustained observations in the global ocean and the oceanic regions surrounding Australia are critical to detecting and attributing climate change and improving projections of changes and their impacts. Research infrastructure in these areas will support a strong blue water and climate science program that addresses priorities identified in the *National Framework for Climate Change Science*<sup>47</sup>.

Enhanced capability in marine observation is equally important for the sustainable management of the marine environment, including the use of biological and seabed resources and the protection of ecosystems that are under threat from human influences. Australia's marine industries, national security and maritime safety also depend on knowledge of our oceans. By enhancing Australia's marine research capability we can advance our understanding of coasts, climate and carbon cycles.

## **Challenges and Assumptions**

An integrated and coordinated approach provides powerful support for the research required to understand and manage our marine environment. A long term commitment with supporting infrastructure is required to sustain and enhance research efforts. There is an increasingly important

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<sup>43</sup> <http://www.climatechange.gov.au/government/initiatives/~media/publications/science/national-framework-cc-science.ashx>

<sup>44</sup> <http://www.opsag.org/pdf/opsag-marine-nation-01.pdf>

<sup>45</sup> <http://www.antarctica.gov.au/science/australian-antarctic-science-strategic-plan-201112-202021>

<sup>46</sup> <http://www.science.org.au/natcoms/nc-ess/documents/ess-report2010.pdf>

<sup>47</sup> <http://www.climatechange.gov.au/government/initiatives/national-framework-science>

need to integrate the marine observations across all of Australia's ocean territory, with emphasis on the discoverability, accessibility and interoperability of associated data streams.

A specific challenge in the marine science capability area is the coordination of activities with other related national collaborative infrastructure to advance scientific cooperation and the sharing of hardware, platforms, modelling and data and information capabilities. The focus for this cooperation should be to achieve scientific outcomes which benefit knowledge and understanding of key issues for lands, coasts, oceans, climate and the carbon cycle.

Increasing effective engagement with, and leverage of, international marine science initiatives under the framework of the *Global Ocean Observing System*<sup>48</sup> is a key to strengthening Australia's marine research capacity and research outcomes. Securing ongoing and long-term support for participation in these initiatives will provide substantial returns for Australia's efforts.

Our ability to manage the vast natural resources of our marine environment depends on understanding our marine biodiversity and the structure and function of our marine ecosystems. This requires knowledge of Australia's biodiversity, including the identity of organisms, their genetic diversity, the relationships between organisms, and their functional role in ecosystems. In this context, a key challenge is to develop innovative rapid assessment technologies for living systems in the marine environment. Strong linkages to the Integrated Biological Discovery and Biological Collections and Biobanking capability areas will be required.

The Australian region, and indeed the Southern Hemisphere, suffers from a paucity of palaeoclimate records, including marine records, and greater effort is required to expand and synthesise these records into regional, hemispheric and global reconstructions of climate. Maintaining and building Australia's capability in palaeoclimate research is an important contribution to global climate science.

Linkages to the Astronomy and Space Science capability area are important because satellite-based remote sensing capabilities are crucial to ocean, climate and cryospheric research efforts. The continued development of advanced sensors and sensor networks is also an underpinning requirement.

The integration of terrestrial and marine observations is required to better understand Australia's vast coastal domains. There is a critical need to identify a fundamental set of observations and data for this purpose. Conducting and coordinating research in the coastal zone represents a significant challenge given the complexity of working across disciplines, communities, jurisdictions and interests.

### ***Specific Requirements***

Investment in ocean observation should be continued and the coverage extended to include the deep ocean, the under sea-ice environment, the Antarctic cryosphere and the oceanic regions surrounding Australia.

Other key infrastructure needs include the continued support for blue water research capacity, as well as access to coastal and ice-breaking marine science capabilities and a marine experimental research capability to support temperate and cold water experimental science.

Linkages to molecular biology technologies and tools, including the 'omics to support marine observations capability is required, especially in the area of ecosystem metagenomics.

Sustained investment is required in the human and physical infrastructure needed to develop enhanced data management and analysis tools, to improve integration across observations, characterisation, and modelling and to increase uptake by end-users including researchers and policy-makers.

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<sup>48</sup> <http://www.ioc-goos.org>

# Terrestrial Systems



## **Description**

Investment in research infrastructure capability for terrestrial systems requires an integrated and interdisciplinary view due to the complex and inter-related nature of the systems themselves. The millennium drought, food price spikes and recent extreme weather and climate events have focused attention on the importance of climate variability and change on terrestrial systems.

A collaborative and integrated research capability is required with observation and surveillance infrastructure coupled with data-intensive analytical techniques. More specifically, the research infrastructure capability should provide a foundation for research into how ecosystems are structured and function, the role they play in providing resources and how they can be managed in a sustainable way.

## **Strategic Impact**

Pressing national and global environmental challenges continue to be strong drivers for innovation and research in Australia. Such challenges include: addressing food, water, resource and biological security; dealing with the impacts of increasing human population; adapting to climate change; and the reduction of greenhouse gas emissions.

Strengthening our understanding of terrestrial systems is vital to the health and sustainability of Australia's environment. A national view of the status and evolution of ecosystems in both natural and managed landscapes within the global context is required. Primary threatening processes that need to be understood include various forms of land degradation, salinity, natural hazards (including floods and cyclones), scarcity of freshwater resources, loss of biodiversity, and climate change. These processes are exacerbated by increasing urbanisation, particularly in the coastal zone.

Long-term observation and experimentation in agricultural and forest systems is essential for understanding terrestrial biogeochemical cycles and the environmental impacts of agriculture and forestry. Investment in this area will bring a renewed focus on Australian soils to address important research questions, such as the potential for carbon sequestration and the sustainability of managed landscapes.

## **Challenges and Assumptions**

It is recognised that improving the integration of data relating to Australia's terrestrial systems is a big task. The degree of difficulty derives firstly from the complexities of the systems being studied and secondly from the number of researchers, organisations and jurisdictions involved in environmental research and management.

Linkages across the environmental capabilities on shared approaches to information management infrastructure should continue to be strengthened. For instance, collaborative development of integrated observing and information systems for the coastal zone will be important for this critical area. eResearch infrastructure provides an enabling platform for data-intensive capabilities across the environmental domain.

In order to improve our understanding of Australia's biodiversity, this capability area will need to interact and link to the Integrated Biological Discovery and Biological Collections and Biobanking

capability areas. This will ensure Australia develops capacity in ecosystem metagenomics as a logical adjunct to the establishment and expansion of terrestrial and marine ecosystem observations. In particular, this will lead to an increased understanding of the genetic diversity and genomic profile of organisms, the relationships between organisms, and their functional role in ecosystems.

In addition, this capability area needs to interact with the Astronomy and Space Science area regarding remote sensing and is reliant on the continued development of advanced sensors and sensor networks.

Investment should be coordinated with key initiatives such as the *National Plan for Environmental Information*<sup>49</sup>, the Bureau of Meteorology's Australian Water Resources Information System<sup>50</sup>, and state government programs (such as the Goyder Institute in South Australia).

### ***Specific Requirements***

Investments to date have made a good start on establishing the necessary long-term observing and information systems. While maintaining existing capacity, there is a need to extend the coverage and to improve the integration.

Key infrastructure needs include:

- extension of the network of baseline sites, 'super sites' and long-term ecological research sites to aquatic ecosystems, the coastal zone and managed landscapes, with agreed measurement protocols
- observing systems to monitor soil condition to enable research into soil carbon sequestration as well as spatial distribution of soils and changes over time, including water storage, carbon dynamics and nutrient availability
- standardisation of methods for measurement and analysis (for example parameters relating to the carbon cycle)
- improved capacity for measurement and monitoring of freshwater ecosystems and biodiversity with increased focus on the function, resilience and response of aquatic ecosystems, including experimental research infrastructure at the ecosystem scale
- provision of enhanced fit-for-purpose models and predictive capabilities
- sensor technologies and networks for improved and coherent measurement of parameters in priority ecosystems
- support for the emerging techniques of environmental metagenomics
- shared approaches to data management and ICT infrastructure to support discovery, access and interoperability of datasets, and national coordination in areas such as developing metadata standards.

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<sup>49</sup> <http://www.environment.gov.au/npei/index.html>

<sup>50</sup> <http://www.bom.gov.au/water/about/wip/awris.shtml>

### **Example: Coastal Systems – need for an integrated approach**

Australia's vast and diverse coastal systems are vital to our population, our economy and national well-being. Already 85 per cent of Australians live in our major state capital cities and regional centres along the coastal fringe and, as our population grows over the next few decades, the demand for urban space, industrial development sites and services in these regions will grow significantly. Much of Australia's industrial, commercial and tourism infrastructure is located along the coast, as are our vital transport hubs.

The pressures imposed by our increasing footprint on coastal systems, combined with the impacts of climate change, present huge challenges for local, state and federal governments as they seek to adapt to and plan for future growth while maintaining the health of our marine, estuarine and terrestrial ecosystems.

The complexity of governance in the coastal zone is mirrored by the complexity of the systems themselves. Their physical, geological, biological, social and economic characteristics interact as drivers of change, components of resilience, and considerations for policy-makers as they seek to achieve ecologically sustainable development.

There are several facilities funded under previous Roadmaps that are responding to these issues at a scope and scale not previously achievable in Australia. These investments have begun to address major inadequacies in our understanding and modelling of the marine, terrestrial, and solid earth components of the coastal zone.

However, there is widespread recognition among research communities and government at all levels that additional focus on coastal systems research is urgently required. The challenge is to avoid spreading available research infrastructure investment too thinly or creating unnecessary duplication. Investments through the marine, terrestrial, solid earth, atmospheric and urban capabilities must be focussed and integrated to provide the maximum scientific impact in high priority coastal system research areas.

Analyses of coastal research needs have recently been made by a number of national and international organisations and committees<sup>51, 52, 53, 54</sup> and these provide useful bases for identification of priority foci and evaluation of specific infrastructure needs.

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<sup>51</sup> [www.aph.gov.au/house/committee/ccwea/coastalzone/report.htm](http://www.aph.gov.au/house/committee/ccwea/coastalzone/report.htm)

<sup>52</sup> [www.environment.gov.au/coasts/iczm/index.html](http://www.environment.gov.au/coasts/iczm/index.html)

<sup>53</sup> Morton et al, *Austral Ecology* (2009) 34, 1–9

<sup>54</sup> Requirements for Global Implementation of the Strategic Plan for Coastal GOOS : IOC-WMO-UNEP-ICSU: Global Ocean Observing System Draft Document.

# Solid Earth



## **Description**

The earth's crust provides many crucial services essential to the wealth and health of society. It is the platform on which we live, the mineral, energy and groundwater resources on which we depend and increasingly serves as a repository for our hazardous wastes. It contains a precious archive of past climates and the history of life. It is also the source of some of the most catastrophic natural hazards faced by the world.

Accurate information about the earth's crust supports both our understanding of the fundamental geological processes and structures, and the manner in which they evolved over time.

Infrastructure is required to allow for the acquisition and study of properties of the earth structures and materials, access and interoperability of large and complex datasets, along with software tools for simulation and modelling.

## **Strategic Impact**

With the collective scale of human activity now rivalling many natural geophysical processes, the earth sciences are providing the framework for understanding how we impact on the functioning of our planet and the sustainability of its resources.

Humanity's relationship with the earth is complex. Natural hazards are driven by the underlying crustal stress regime and other earth properties. These in turn influence the distribution of mineralisation, energy and the capacity to store waste including carbon dioxide. Improved understanding of the earth's crust will allow us to better use its resources in a sustainable manner.

Earth sciences contribute to:

- advancing our understanding of 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 and energy resources (including potential energy storage and sources)
- characterising the extent and nature of Australia's groundwater resources to improve our understanding and the potential for increased use in a period of climatic uncertainty
- providing understanding and early warning of natural hazards such as earthquakes and tsunamis
- supporting coastal zone research by accurately defining vertical and horizontal position, and by describing the nature and erosion or advance of the coastline.

The Australian continent has one of the most integrated and instrumented continental-observing platforms on earth. Extending the nation's expertise to the surrounding deep ocean floors and the deepest levels of the accessible crust will enhance our ability to resolve its physical state. This research will improve our understanding of how the crust will respond to interventions, such as geothermal energy production, carbon dioxide storage, isolation of dangerous wastes and earthquake hazards.

## ***Challenges and Assumptions***

Previous investment has facilitated the implementation of an integrated infrastructure system for earth science by deploying a range of capabilities in data acquisition, management, modelling and simulation across the geospatial and geoscience spectrum. A future challenge will be to create a fully integrated earth observatory.

Considerable effort is being devoted by the geoscience community to the development of capabilities for managing and sharing large datasets and the tools to analyse data and develop models. Significant potential exists for the wider application and development of these capabilities across other research areas.

In order to address these challenges, this capability area will need to have strong linkages to the Astronomy and Space Science, Sustainable Energy and the other environmental capabilities. It is also reliant on continued development of advanced sensors and sensor networks.

## ***Specific Requirements***

Further support for this capability area will maintain Australia's world leading abilities in this area and sustain the collaborative behaviours of this community. Sustained and enhanced data acquisition, data management and modelling and simulation capabilities building on those being implemented through current investments is also needed. In addition, support for new data streams will be required.

In order to support the development of this capability area, additional capacity should be considered in:

- earth imaging to provide an equipment pool deployable to enable greater coverage and additional geophysical data across large areas of Australia
- geospatial systems (including both physical and eResearch infrastructure), to improve accuracy and time resolution for geoscience and other research areas that require spatial data
- earth model construction to allow simulation codes to interoperate with e-earth infrastructure
- a subsurface earth observatory that allows researchers access to instrument, log and monitor for a variety of purposes including geothermal energy, paleoclimatology, groundwater and carbon dioxide storage
- dedicated ICT, in particular data storage and software engineering support to achieve the transition of virtual libraries to virtual laboratories
- geochemical instruments, including a dedicated earth science synchrotron beam line facility.

## Urban Settlements



### ***Description***

Understanding of the physical, social, economic and ecological aspects of urban settlements is essential in improving the environmental sustainability of cities and other urban areas, and improving economic prosperity and quality of life.

The Urban Settlements capability will require facilities that enable the collection and integration of datasets covering the range of human activities by those working, investing and living in urban areas. The capacity to understand the physical and social aspects of urban settlements, as well as acquiring an understanding of the management of the interactions between people and their urban environments are required to solve a myriad of future research challenges.

### ***Strategic impact***

While urban settlements range from cities and smaller urban areas to households, a few major urban settlements host the vast proportion of the Australian population and a similar share of the nation's production and consumption, economic activity and social interaction. The long term environmental, social and economic sustainability of Australia's urban settlements will define the lived experience of the population, its environmental impact and its economic prosperity.

Difficult issues of resource consumption (including energy and water), waste production (including greenhouse gases), transport, food security, liveability, housing, employment and economic activity, urban concentrations on the coast, health and well-being are being faced in all major Australian settlements.

To understand urban settlements from research, policy, management and design perspectives, it is essential to have reliable and nationally consistent data in which settlements can be described as systems. That is, both as physical sites whose systems may be the subject of scientific analysis, and as social and economic sites in which human behaviours, production and consumption occur that themselves have consequences for environmental, social and economic sustainability.

### ***Challenges and assumptions***

Understanding and managing the complexity of modern cities is impossible without strong cross-disciplinary approaches which span the natural and social sciences and the humanities and are enabled by eResearch infrastructure.

Relevant datasets include demographic, resource consumption, transport, housing, space usage, socio-economic status and activities, and well-being data. Integrating these datasets demands engagement with multiple public and private sector interests who hold the data and utilise research outcomes, and with a wide range of disciplines interacting within a broadly-defined urban studies field. Coordination of data capacities and infrastructure will be vital.

An effective capability in this area would interact and link with many other capability areas, including the range of health and environmental capabilities as well as energy, biosecurity and cultures and communities.

### ***Specific requirements***

Recent investment in this area represents the first substantive attempt to organise data into an integrated research infrastructure for urban research. As this investment matures, there will be a need to develop further areas of focus, to attend to emerging gaps and consider extension for greater national coverage.

In addition, infrastructure is required to address outstanding issues of national consistency and interoperability across data sources, such as geo-coding and other adjustments to routinely collected data to enhance access for research use. There is also a need to support the ongoing maintenance of and access to critical data.

Improved coordination is needed to better support the coherence and excellence of urban research in Australia.

Investment is needed in facilities for modelling social and environmental interactions and this must involve linkages to the environmental observation capabilities outlined in this roadmap.

# Atmospheric Observations



## **Description**

The atmosphere is a critical component of the environment in which we live and changes in its state impact the daily lives of Australians. Atmospheric circulation systems connect key regions of the world interacting with processes in the ocean, over ice and on land.

An atmospheric observations capability is required to support the research activities that build our understanding of atmospheric processes, particularly for climate research activities. The capability will involve an observing network to monitor the atmospheric composition, atmospheric evolution and clouds and rainfall.

## **Strategic Impact**

Atmospheric observations are routinely undertaken by operational and research agencies. Through optimising and expanding Australia's ability to utilise this data by the whole atmospheric research community, significant gaps in measurements of greenhouse and reactive gases, cloud, and aerosols can be addressed. This will increase our ability to predict atmospheric behaviour and improve our understanding of how the atmospheric component of the climate system behaves. This capability is central to the *National Framework for Australian Climate Change Science*<sup>55</sup>.

Increasing concentrations of greenhouse gases (GHGs) and changing aerosol concentrations are driving significant changes in global and regional climate. Regional differences in the concentrations and isotopic composition of GHGs can be used to infer the spatial and temporal variability in their sources and sinks and thus to inform mitigation strategies. Knowledge of the sources and sinks of GHGs is fundamental to projections of climate change and are important in international negotiations in the *United Nations Framework Convention on Climate Change (UNFCCC)*<sup>56</sup>.

Potential changes in rainfall are one of the most critical issues facing Australia. Rainfall patterns are controlled by the large-scale atmospheric circulation, internal modes of variability and by local and regional processes, including cloud processes. The simulation of circulation features in climate models critically depends on the accurate depiction of cloud and aerosol processes. Thus, major uncertainties in cloud and aerosol processes affect rainfall prediction across the country and new observational programs on regional cloud processes, aerosol concentrations, their interactions and representation in models will lead to substantial further progress.

Regular high quality cloud and aerosol measurements will provide an opportunity for Australian research to contribute to the global understanding of cloud affects and feedbacks as well as the aerosol direct and indirect (via modification of cloud properties) radiative effects. Australia is well placed to lead long-term cloud and radiation measurement sites in the tropics and high latitude/polar regions of the Southern Hemisphere.

## **Challenges and Assumptions**

The capability required to advance the most critical issues in this area requires comprehensive atmospheric measurements of a set of interconnected parameters, ranging from GHGs to aerosols,

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<sup>55</sup> <http://www.climatechange.gov.au/government/initiatives/national-framework-science.aspx>

<sup>56</sup> [http://unfccc.int/essential\\_background/convention/background/items/2853.php](http://unfccc.int/essential_background/convention/background/items/2853.php)

to reactive gases to cloud properties and to the associated rainfall distribution at a range of sites. Some important components of the required observational sites already exist through national and international investments. The opportunity and challenge is to build on the existing capabilities to provide the comprehensive measurements.

There are three existing measurement sites, each covering part of the required comprehensive measurement capabilities, which can be leveraged for the proposed enhancement – the Cape Grim Baseline Air Pollution Station (CGBAPS, operated by the Bureau of Meteorology), the Darwin Climate Research Station and the Brisbane Radar Facility. Completing our measurement capabilities over land at the above three sites will advance many of the issues highlighted above. Due to the vast and difficult-to-access Southern Ocean, increasing our knowledge of clouds and their interaction with aerosols will continue to be a challenge.

The estimation of the emissions, transport and chemistry of trace gases and aerosols from large-scale diffuse sources such as fires and wind-blown dust is beginning to make use of remote sensing technologies such as satellites. Ground-truthing is an essential step in order to make effective use of these products over the Australian landscape. This step relies on high quality in situ observations of trace gases and aerosol chemical components and size distributions. A key challenge is the setting of a national protocol for the measurement of fine particles.

The quality and quantity of satellite data on many aspects of the atmosphere have increased dramatically in recent years. These data are particularly important in the sparsely observed southern hemisphere and today many parameters can be measured globally from satellites. However, Australian investment in the exploitation of these data through its analysis, verification and integration with in situ data and its assimilation into models has not kept pace with the increased international capability. Access to these increasingly important data streams and their exploitation for Australia's benefit requires strong participation in both international and national programs to exploit both the observations and their use in modelling<sup>57</sup>, through the Astronomy and Space Science capability area.

### **Specific Requirements**

Addressing these major opportunities and challenges requires an atmospheric composition observing network that would combine in situ and remote sensing infrastructure and document trends in GHG and aerosol concentrations, as well as cloud and precipitation structures.

For estimation of the regional sources and sinks of GHGs, high quality stations such as CGBAPS need to be supplemented by higher spatial resolution concentration measurements of GHGs, as well as surface fluxes of carbon dioxide. Also, future satellites measurements, when combined with high quality in situ measurements like those provided by the high quality stations and the network proposed here, will result in a step change of the scientific capability to infer national and regional GHG sources and sinks.

Therefore, consideration should be given to a network of *in situ* automated GHG and aerosol observing stations and *in situ* radiation measurements, co-located with existing weather and/or flux tower networks.

The provision of a smaller but mobile version of the key observing systems above is technically feasible and would enable the research questions to be transferred to the critically important Southern Ocean region through deployment on islands (for example Macquarie Island) or ships (for example the Marine National Facility and the *Aurora Australis*). This mobile capability would enable researchers to focus on key source and sink processes such as carbon capture and storage in the major coal/gas basins.

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<sup>57</sup> <http://www.science.org.au/reports/documents/EOSfinal.pdf>

There is a requirement for increased capability to utilise satellite data directly and in earth system modelling activities this would need strong participation in international satellite programs, in situ verification/calibration projects and infrastructure to process, interpret and distribute the related information to underpin a wide range of climate and environmental research activities.

### **Example: Climate and Carbon – need for an integrated approach**

Australia, as a nation extending from the tropics to Antarctica, is strongly influenced by global and regional climate variability and change. This results from interactions between all elements of the climate system on local, regional and global scales, including the atmosphere, the oceans, the terrestrial environment and the cryosphere. Increasingly, human activities are interacting with this natural variability and driving further global change.

Prediction of inter-annual climate variability, Australia's drought-flood cycle, and projections of longer term climate change, including changes in climate phenomena and the intensity and frequency of extreme events, require a sound understanding of climate system science and the development of robust models. Climate change science has been and will continue to be essential in supporting the three pillars of the Australian Government's climate change policy: action to reduce greenhouse gas emissions, action to adapt to climate change that we cannot avoid, and action to help shape a global solution.

Sound long-term observational data across all of the earth's natural domains is critical to providing robust predictions of future climate and the impacts on the natural and built environment. Most critical are the storage and fluxes of heat, water and carbon and other radiatively-active gases within and between the atmosphere, ocean, terrestrial environment and the cryosphere. These observations need to include modern in situ observations, satellite observations, data archaeology (the recovery and digitisation of historical records) and paleo-climate records.

The integration of observations from the many data streams is critical to fully understand the cycling of heat, water and carbon and their interactions and impacts with the natural and built environment. In order to investigate these pressing issues, the environmental capabilities outlined in this Roadmap, including Marine Environment, Terrestrial Systems, Solid Earth, Urban Settlements and Atmospheric Observations, must work together to provide high quality, interoperable, accessible, discoverable and model ready data streams.

This will be assisted through the Digitisation Infrastructure capability and the key underpinning eResearch infrastructure requirement to provide data systems that can be used efficiently and effectively for domain specific studies and for the broader integrative modelling that is required.

# Appendix A – Details of the 2011 Roadmap Development Process

The development of the 2011 Strategic Roadmap for Australian Research Infrastructure took place primarily in the first half of 2011. There were three key stages of the document's development in the following order:

- Release of a Discussion Paper for consultation
- Release of an Exposure Draft of the 2011 Strategic Roadmap for Research Infrastructure for consultation
- Release of the final 2011 Strategic Roadmap for Australian Research Infrastructure.

The 2011 Roadmap was developed under the strategic leadership of the National Research Infrastructure Council and the roadmapping process was designed to allow for the widest possible consultation.

A key aspect of the roadmapping process was the use of Expert Working Groups to provide specialist advice to the department on developments in research and priorities for research infrastructure.

Six Expert Working Groups were established using the National Research Priorities (NRPs)<sup>58</sup> as an organising principle, with additional groups for 'Understanding Cultures and Communities' and 'eResearch Infrastructure'.

The formation of the Expert Working Groups around the NRPs with the two additional groups reflects the process taken to create both the 2006 and 2008 Roadmaps.

The six Expert Working Groups in the 2011 process were as follows:

- Environmentally Sustainable Australia
- Promoting and Maintaining Good Health
- Frontier Technologies
- Safeguarding Australia
- Understanding Cultures and Communities
- eResearch Infrastructure

The department sought nominations from a wide range of stakeholders in late 2010 and received more than 400 nominations. Members of these 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 views of their peers and other stakeholders.

A list of members of each of the Expert Working Groups is below.

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<sup>58</sup> <http://www.innovation.gov.au/AboutUs/KeyPublications/Documents/InnovationPortfolioFactSheets.pdf>, pg 140

## ***Environmentally Sustainable Australia***

Dr John Gunn (Chief Scientist, Australian Antarctic Division) – Chair  
Professor Vassilios G Agelidis (The University of New South Wales)  
Dr Andrew Barnicoat (Geoscience Australia)  
Dr John Church (CSIRO)  
Dr Colin Creighton (Fisheries Research and Development Corporation and the Grains Research and Development Corporation)  
Dr Nick D'Adamo (UNESCO)  
Professor David Day (Flinders University)  
Professor Stephen Dovers (The Australian National University)  
Professor Bronwyn Gillanders (The University of Adelaide)  
Mr Warwick McDonald (Bureau of Meteorology)  
Dr Phillip McFadden  
Dr Neil McKenzie (CSIRO)  
Dr Tony Press (Antarctic Climate and Ecosystems Cooperative Research Centre)  
Dr Russell Reichelt (Great Barrier Reef Marine Park Authority)  
Professor Paul Sanders (Queensland University of Technology)  
Professor Mike Sandiford (The University of Melbourne)  
Dr Brett Summerell (The Royal Botanic Gardens and Domain Trust)  
Professor Grant Wardell-Johnson (Curtin University)

## ***Promoting and Maintaining Good Health***

Professor Mike Calford (Deputy Vice-Chancellor (Research), The University of Newcastle) – Chair  
Professor Judith Clements (Queensland University of Technology)  
Professor Simon Foote (University of Tasmania)  
Professor Doug Hilton (Walter and Eliza Hall Institute of Medical Research)  
Dr Paul Jelfs (Australian Bureau of Statistics)  
Professor Louisa Jorm (University of Western Sydney)  
Professor Paul Keall (The University of Sydney)  
Professor Peter Leedman (The University of Western Australia)  
Professor Julio Licinio (The Australian National University)  
Professor Kerin O'Dea (University of South Australia)  
Professor Ian Smith (Monash University)  
Dr Ron Weiner (Australian Nuclear Science and Technology Organisation)

## ***Frontier Technologies***

Dr Calum Drummond (Group Executive, Manufacturing, Materials and Minerals, CSIRO) – Chair

Dr Phil Diamond (CSIRO)

Professor Lorenzo Faraone (The University of Western Australia)

Associate Professor John Fletcher (The University of New South Wales)

Dr Marie-Claude Gregoire (Australian Nuclear Science and Technology Organisation)

Professor Tanya Monro (The University of Adelaide)

Professor Paddy Nixon (University of Tasmania)

Emeritus Professor John O'Callaghan (The Australian National University)

Professor Mary O'Kane (NSW Chief Scientist and Scientific Engineer)

Professor Bernard Pailthorpe (The University of Queensland)

Professor Steven Praver (The University of Melbourne)

Professor Judy Raper (University of Wollongong)

Professor Robert Williamson (The Australian National University)

## ***Safeguarding Australia***

Dr Alastair Robertson (Group Executive, Food, Health and Life Science Industries, CSIRO) – Chair

Dr Laurie Besley (National Measurement Institute)

Mr Brett Biddington (Biddington Research Pty Ltd.)

Dr Regina Fogarty (Industry & Investment NSW)

Associate Professor James Gilkerson (The University of Melbourne)

Professor Andrew John Goldsmith (University of Wollongong)

Dr John Percival (Defence Science and Technology Organisation)

Professor Susan Pond (Commercialisation Australia)

Professor John Roddick (Flinders University)

Dr John Stambas (Deakin University)

Professor Richard Tay (La Trobe University)

Professor Sue Thomas (Charles Sturt University)

Associate Professor Colin Wastell (Macquarie University)

Professor Tony Watson (Edith Cowan University)

## ***Understanding Cultures and Communities***

Professor Rae Frances (Dean of Arts, Monash University) – Chair

Professor Pal Ahluwalia (University of South Australia)

Ms Margaret Anderson (History SA)

Dr Paul Arthur (The Australian National University)

Professor Alison Bashford (The University of Sydney)

Professor Ann Capling (The University of Melbourne)

Mr Alec Coles (Western Australian Museum)

Distinguished Professor Stephen Crain (Macquarie University)

Dr Rebecca Johnson (Australian Museum)

Dr Marcus Lane (CSIRO)

Ms Anne-Marie Schwirtlich (National Library of Australia)

Dr Luke Taylor (Australian Institute of Aboriginal and Torres Strait Studies)

Dr Nicholas Thieberger (The University of Melbourne)

Professor Mandy Thomas (The Australian National University)

Ms Gemma Van Halderen (Australian Bureau of Statistics)

Professor Andrew Wells (Australian Research Council)

## ***eResearch Infrastructure***

Professor Attila Brungs (Deputy Vice-Chancellor and Vice-President (Research), University of Technology, Sydney) – Chair

Professor Paul Bonnington (Monash University)

Professor Andrew Cheetham (University of Western Sydney)

Dr Joanne Daly (CSIRO)

Mr Peter Nikolettatos (Curtin University)

Mrs Linda O'Brien (Griffith University)

Professor Andy Pitman (The University of New South Wales)

Mr Antony Stinziani (Geoscience Australia)

Ms Judy Stokker (Queensland University of Technology)

Dr Darrell Williamson (CSIRO)

Dr Judith Winternitz (Department of Broadband, Communications and the Digital Economy)