Australian Government

National Research Infrastructure Roadmap

National Research Infrastructure Capability Issues Paper

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1 Introduction

The Australian Government has requested the development of the 2016 National Research Infrastructure Roadmap (2016 Roadmap) to determine Australia's national research infrastructure needs over the next decade to underpin our national research effort.

The 2016 Roadmap is being developed by an Expert Working Group (EWG)[1] led by Australia's Chief Scientist, Dr Alan Finkel AO. The EWG and the 2016 Roadmap are supported by a broad based Government Taskforce hosted by the Department of Education and Training with the support of the Department of Industry, Innovation and Science, the Department of Health and the Department of the Environment and Energy.

Since 2005, the Government, in conjunction with stakeholders, has developed three strategic research infrastructure roadmaps[2] to guide national investment in research infrastructure. Each roadmap has looked forward over a ten year horizon, and it is now time to consider new and emerging areas in the research environment requiring national scale investment.

Stakeholder engagement has been key to the development of earlier research infrastructure roadmaps, which have kept Australian research at the leading edge and internationally competitive. This collaborative approach to identifying Australia's national research infrastructure needs has created a network of highly effective and efficient[3] facilities that are strategic and cross-disciplinary.

The 2016 Roadmap will build on previous roadmaps by developing a shared vision for national research infrastructure to ensure Australia remains competitive in a rapidly evolving global environment.

[1] Information on the EWG is available at Attachment B.

[2] Previous roadmaps:

- 2006 National Collaborative Research Infrastructure Strategy (NCRIS) Strategic Roadmap;
- 2008 Strategic Roadmap for Australian Research Infrastructure; and
- 2011 Strategic Roadmap for Australian Research Infrastructure.

[3] http://www.education.gov.au/ncris-projects-efficiency-review

2 2016 National Research Infrastructure Roadmap

2.1 Scope

For the purpose of the 2016 Roadmap:

> National research infrastructure comprises the assets, facilities and services to support research that drives leading-edge innovation in Australia. It is equally accessible to publicly and privately funded users across the country, and internationally.

The 2016 Roadmap will guide future investment in national research infrastructure by ensuring a coordinated approach across Government and key stakeholders that will:

- concentrate effort nationally on areas of greatest strategic impact
- increase collaboration within the research system and between it and end users of research such as industry and business and the wider community, and
- reduce duplication and sub-optimal use of resources arising from lack of coordination.

As in earlier roadmaps, consultation with the research community and other key stakeholders will help the EWG to identify the priority research infrastructure investments needed to support innovative research in fields of strategic priority that will enable Australia to optimise its research effort.

2.2 Purpose of this Issues Paper

This National Research Infrastructure Capability Issues Paper (Issues Paper) sets out the proposed capability requirements that will inform the development of the 2016 Roadmap. This will be accompanied by extensive consultation with key stakeholders, from late July to early September 2016, leading to the development of a 2016 National Research Infrastructure Roadmap Exposure Draft. The 2016 Roadmap Exposure Draft will set out the key priority areas for investments in creation, re-investment, decommissioning or defunding of projects and facilities. Following further consultation in the later part of 2016, the final 2016 Roadmap, setting out a framework and investment strategy for the next ten years, will be provided to Government.

To assist with the development of the Issues Paper, the EWG brought together teams of experts drawn from across the research community to provide advice on capability focus areas[4]. The capability experts, through their extensive know-how and targeted consultations with the research community and other key stakeholders, have made a significant contribution to the development of this Issues Paper.

The purpose of this Issues Paper and requested submissions is to make sure the capability areas are the right ones and that the areas for future development, which may include ongoing support of existing activity, as appropriate. This stage is not about funding or governance, or the identification of facilities, projects or specific items of infrastructure, or where they should be located, or which organisations might operate or contribute. These elements are important and will be explored in the coming months with the development of the 2016 Roadmap.

[4] Information on the National Research Infrastructure capability experts is available at https://www.education.gov.au/2016-national-research-infrastructure-roadmap

It is not possible to discuss capability without reflecting on existing national facilities and their current and future role in underpinning Australia's future research needs. As a result, capability areas have been aligned with existing national research infrastructure. This has assisted in identifying new capability requirements and areas of future national research infrastructure development.

One of the aims of this Issues Paper and the associated consultation process is to gain a shared understanding of how public investment in research infrastructure will be prioritised so as to make a significant difference to Australia's research and innovation outcomes aligned to our National Science and Research Priorities[5]. This will be followed-up in the next stage of the 2016 Roadmap as we explore the identification of the specific research infrastructure required, and the most efficient and effective way to provide it.

Ultimately, future funding to renew, expand or improve existing investments under the National Collaborative Research Infrastructure Strategy (NCRIS) or other national infrastructure such as the ANSTO OPAL Reactor, will depend on the strategic investment decisions of the Government.

This Issues Paper is the first step in establishing a shared view of the capabilities that require national research infrastructure to support current, new and emerging areas of research. In framing this Issues Paper, the EWG has considered the advice provided by the capability experts, international trends, the collaborative nature of cross-disciplinary research and the important role of research infrastructure in fostering collaboration and innovation.

This Issues Paper has been developed to encourage discussion and to ensure that stakeholder views are considered in the development of the 2016 Roadmap. Your views on the national research infrastructure capability requirements outlined in this Issues Paper are important. You are encouraged to provide a submission and details regarding how to make a submission are available in **Attachment A**.

[5] Mapping the research infrastructure capability focus areas against the National Science and Research Priorities was undertaken as part of the development of this Issues Paper and can be found at Attachment C.

3 National Research Infrastructure Policy Issues

3.1 Capability areas

The capability focus areas which have been informed by the capability experts are based on the National Science and Research Priorities and are explored in the Issues Paper as:

- Health and medical science
- Environment and natural resource management
- Advanced physics, chemistry, mathematics and materials
- Understanding cultures and communities
- National security
- Underpinning research infrastructure
- Data for research and discoverability

Question 1: Are there other capability areas that should be considered?

3.2 Governance

There is a strong emerging theme around leadership to determine priorities for research infrastructure. In some disciplines this has been in part addressed through decadal plans. However the outcomes are often intentionally aspirational and outline objectives for the discipline, rather than providing a prioritised list for infrastructure investment.

Areas such as data for research and discoverability have been identified as pervasive across the research system. Ensuring that there is cooperation and consultation across capability areas to provide a whole-of-research system response in areas such as the environment, cultures and communities, characterisation and fabrication has also emerged as a key theme.

In defining the optimal governance model key characteristics could include:

- Focus on benefits and outcomes
- Access models, both private and public
- Level of interoperability across the research infrastructure system
- Strategic approach to whole-of-life costs including defunding or decommissioning
- Collaboration and networking
- Intellectual property and moral rights
- Resource management including co-investment, skills and training, and
- Frameworks for accountability.

Question 2: Are these governance characteristics appropriate and are there other factors that should be considered for optimal governance for national research infrastructure?

3.3 International

The international dimension of research infrastructure is of ever increasing importance. Cutting edge research in numerous research domains requires access to globally unique research infrastructure that cannot be replicated nationally. Additionally, maximising Australia's investments in research infrastructure often requires linking into international projects and consortia. For example, Australia's Integrated Marine Observing System is greatly enhanced by its integration into the Global Ocean Observing System.

Australia's engagement in international research infrastructure includes a number of dimensions:

- Global networks – To maximise Australia's investments in research infrastructure by linking to comparative international projects and leveraging international funding.
- A seat at the table – To participate and to influence decisions, in some international projects requires investment in that area, either in international projects or equivalent national projects.
- The national interest – Australia can often provide a unique perspective to global problems, while international projects can help Australia see its own research problems with a fresh perspective.
- Meeting the nation's obligations – Contributing to international research infrastructure and projects in order to draw on the broader outcomes and benefits.
- Researcher access – Access to international research infrastructure has been handled on a by researcher basis, except where a research sector or international facility requires more binding and substantial agreements[6]. However, with no general international research infrastructure access program, and the increasing internationalisation of research infrastructure, the need for research infrastructure funding to enable access to international facilities must be considered and prioritised.

Question 3: Should national research infrastructure investment assist with access to international facilities?

Question 4: What are the conditions or scenarios where access to international facilities should be prioritised over developing national facilities?

3.4 Skills and training

The ongoing sustainability of national research infrastructure capability is largely driven by the specialised skill and quality of the staff supporting the project or facility and the effective engagement of researchers using the facility.

A key issue identified across the capability areas is that the demand for highly skilled technical and research staff has not been met by the supply. While there is some commonality across the capability areas such as data management and analysis, there are also pockets of highly specialised capability that service relatively small research communities such as some areas of characterisation[7].

Similarly, training researchers, particularly early career researchers, to take advantage of national

[6] Such as in astronomy, synchrotron science and Australia's associate membership to the European Molecular Biology Laboratory (EMBL).

[7] Specifically, the individual techniques and disciplines undertaken under the broad capability of characterisation.

research infrastructure investments is increasingly critical. Historically this has been considered an issue related to the development of the research workforce rather than a research infrastructure issue.

As research outcomes become increasingly driven by access to complex research infrastructure, the Government's investments will be maximised by providing access and training to researchers, who in turn are skilled in utilising the data generated from these complex analytical tools and services.

Question 5: Should research workforce skills be considered a research infrastructure issue?

Question 6: How can national research infrastructure assist in training and skills development?

Question 7: What responsibility should research institutions have in supporting the development of infrastructure ready researchers and technical specialists?

3.5 Access

The value of the national research infrastructure system is derived, in large part, through access to research infrastructure by researchers and other end users of research such as industry. Broad accessibility enables the greatest possible use of research infrastructure facilities, and maximises the value of the Government's investment in these facilities.

Considerations of research trends and capabilities in this Issues Paper have been developed through the prism of accessibility for: merit-based public-sector Australian research; merit-based or partial cost recovery based public-sector international research; and the private sector at partial or full cost recovery.

The principles that underpin access to national research infrastructure need to be transparent and equitable while maintaining priority for the very best research, in the national interest.

Question 8: What principles should be applied for access to national research infrastructure, and are there situations when these should not apply?

3.6 Defunding and decommissioning

Defunding and decommissioning national research infrastructure is an area where governments both nationally and internationally have struggled to develop practical approaches. These are critical elements to the whole-of-life costs of research infrastructure as governments have finite resources to support research overall. In the context of the 2016 Roadmap, the level of priority given to a capability and the associated research infrastructure could result in defunding or decommissioning of existing activity.

Defunding, for the purposes of this Issues Paper, refers to the cessation of Australian Government funding for a particular project, acknowledging that this funding is critical to attracting co-investment. In this context it would be important to identify an appropriate pathway and timeframe that may result in alternative funding or transition to another facility or project or transition to a single institution or termination of activity.

Decommissioning, on the other hand, is a specific decision to shut down a piece of research infrastructure. For the Australian Government, this is usually related to facilities it owns and operates through the publicly funded research agencies. By taking the decision to decommission a research infrastructure facility, the Australian Government is stating that activity is no longer wanted.

Decommissioning and defunding can both be considered as part of the normal life cycle of national research infrastructure. For example, over time equipment, technology, processes or facilities become obsolete, ubiquitous or are superseded.

Under both decommissioning and defunding, it is important to negotiate an exit strategy with key stakeholders and, importantly, ensure the transition of key skills.

Question 9: What should the criteria and funding arrangements for defunding or decommissioning look like?

3.7 Funding for research infrastructure

Research infrastructure represents large financial investments, both in initial capital investment and in operational costs. The role of Government is as key investor with patient capital that will, over long timeframes, achieve significant returns on investment and spill-over benefits. Historically, Australian national research infrastructure investment has been made through Australian Government grants, supported by significant co-investment by state and territory governments, universities and the private sector.

In December 2015, the Australian Government announced the National Innovation and Science Agenda, providing ongoing operational funding for the existing National Collaborative Research Infrastructure Strategy (NCRIS) network and funding over a ten year timeframe for the Australian Synchrotron and the Square Kilometre Array (SKA). On the basis that a National Research Infrastructure Roadmap would provide a strategic and prioritised approach to future investment, capital funding was not included.

In times of fiscal constraint, governments internationally are looking at new ways to fund research infrastructure outside the traditional grants paradigm.

Question 10: What financing models should the Government consider to support investment in national research infrastructure?

3.8 Standards and accreditation

As the focus on maximising the benefits of research has intensified, ensuring that relevant industry standards and accreditation are achieved has become increasingly important to enable the translational benefits and efficiency gains from research to be fully realised. For a wide range of research infrastructure capabilities standardisation and validation of the quality of processes and measurements, while costly and time consuming, are critical to maintaining a leading edge. While a number of capability areas such as nanofabrication have accepted the need for accreditation to benchmark their processes and services, there needs to be greater awareness and acknowledgement of the importance of standards and accreditation not only to the research effort, but importantly to meet industry needs.

Question 11: When should capabilities be expected to address standard and accreditation requirements?

4 Capability Focus Areas

Chapters 5 to 11 of the Issues Paper cover the capability focus areas based on the following elements:

- A brief introduction and summary of the capability focus area.
- Emerging directions and the trends that will impact research in the capability focus area over the next decade.
- Details of current and emerging capabilities and how they can meet these emerging directions.
- Possible future infrastructure aligned to capability areas.
- An overview table, summarising current capabilities and examples of possible future capabilities, as well as areas that are proposed to be explored further in the 2016 Roadmap.

In framing the capability focus areas a number of common themes have emerged. As a result some themes will appear under more than one capability focus area. This reflects the pervasive nature of national research infrastructure capability across the research landscape.

As you might expect, data is everywhere and dealt with from both a user perspective within the capability areas and as an enabling national infrastructure itself in Chapter 11 – Data for Research and Discoverability.

The lists of trends and capabilities presented in the following chapters are not intended to be exhaustive and are not prioritised. Existing or proposed research infrastructure identified in conjunction with capability areas does not imply priority or potential future funding. Current arrangements, including the organisations undertaking the management and operation of projects or facilities are subject to future review.

While each section contains questions designed to probe the assumptions, findings and proposed future areas for development in the 2016 National Research Infrastructure Roadmap, the following are general questions concerning national research infrastructure more broadly.

Question 12: Are there international or global models that represent best practice for national research infrastructure that could be considered?

Question 13: In considering whole of life investment including decommissioning or defunding for national research infrastructure are there examples either domestic or international that should be examined?

Question 14: Are there alternative financing options, including international models, that the Government could consider to support investment in national research infrastructure?

The capability areas and supporting national research infrastructure prioritised in both the Exposure Draft and final 2016 Roadmap will largely be dependent on the feedback from the consultations undertaken and submissions received by the EWG as well as ongoing analysis and research undertaken by the Roadmap Taskforce over the coming months.

Details on how you can make a submission can be found in **Attachment A**. Information on the consultation program for the development of the 2016 National Research Infrastructure Roadmap can be found by visiting www.education.gov.au/2016-national-research-infrastructure-roadmap.

5 Health and Medical Science

The Health and Medical Science capability is characterised by national research infrastructure made up of core research infrastructure run by experts, with a strong collaborative ethos to work with public and private sector researchers. This infrastructure links expensive, specialised capabilities in a number of co-ordinated national nodes, ensuring that Australian researchers have access to the latest research infrastructure and importantly to experts in their capability.

The lists of capabilities presented here are neither exhaustive nor prioritised.

5.1 Emerging Directions

5.1.1 Big health data

Big data collections are not new – state and federal, institutional and patient level data holdings are vast. There are also large amounts of data coming from genomics, proteomics and other large scale analytical technologies (‘omics) that benefit research. Linking these collections in ways that are meaningful to researchers, and can subsequently be applied and translated into trials, clinical practices and public health interventions and policies will create new opportunities to solve complex health and social problems, including Indigenous health outcomes.

Opportunities are especially present for disease prevention, design and clinical trialling of treatments and to study the impact of innovation. These opportunities can be enhanced by linking data, including in real time, with data sets outside of health such as justice, education or geospatial. These powerful linkages could be achieved through a national networked approach to existing research and administrative data.

5.1.2 Large bio models

It can be argued that Australia needs a larger capacity for structural biology – a branch of science combining molecular biology, biochemistry, and biophysics. This expertise is concerned with the molecular structure of biological macromolecules, especially proteins and nucleic acids, how they acquire the structures they have, and how alterations in their structures affect their function.

5.1.3 Translation – opportunities for biopharmaceutical and other novel therapies

There is an increasing determination to translate research outputs such as novel molecular candidates or clinical observations into health and commercial outcomes through animal models, proof-of-concept studies, computational models and clinical trials.

5.1.4 Imaging – tracer development

Positron Emission Tomography (PET) using radioactive tracers has become a key tool for functional biomedical imaging over the past decade. PET is an important research tool to map human brain and heart function, and to support drug development. Its future evolution is dependent on development of new radio-nucleotide tracers to maximise new developments in PET scanning.

Imaging technologies beyond PET are covered in the Chapter 7 Advanced Physics, Chemistry, Mathematics and Materials.

5.1.5 Research quality management system

All of the emerging capability directions would benefit from the implementation of an Australia-wide research quality management system (rQMS) infrastructure, which aligns academic research with required industry standards. It would provide international medical and research industry standards training for students and researchers and build reputational value and quality for the Australian research product for end-users.

5.2 Current Capability and Emerging Capability Needs

5.2.1 Biologics capabilities

Biologics, also known as biopharmaceuticals, encompass a range of compounds including recombinant DNA and protein based drugs and vaccines. Biologics as a class of human therapeutics have risen to prominence over the last few decades following the development of recombinant DNA and the technologies that allow the production at large scale by host cells of large protein molecules.

Examples of biologics include protein replacement therapies and the humanised monoclonal antibodies, over fifty of which have been approved for the treatment of multiple diseases, principally cancer and inflammatory diseases. The success of the biologics as a class of therapeutics is such that six out of the world's ten top selling pharmaceuticals are now biologics, many of them being monoclonal antibodies.

There is a need to enhance research infrastructure capability in a focussed and coordinated national effort to translate high quality research into the clinic. The infrastructure capability needed includes enhanced production of high-quality recombinant proteins for pre-clinical development studies. These studies include proof-of-concept evaluation of therapeutic proteins, antibodies and vaccines and the associated validation of candidate products. High-quality recombinant proteins are essential for many other spheres of biomedical and biochemical research, including structural biology, targeting anti-tumour particles for precision medicine, analytical development and in the agricultural biotechnology and biosecurity areas.

5.2.2 Novel therapy capabilities

Using human cells as therapeutic agents is a rapidly growing field both in Australia and internationally. It is a field in which Australia has some leading researchers who are highly regarded. One particularly exciting area is immunotherapy, a type of cancer treatment designed to boost the body's natural defences to fight cancer. Immunotherapy can use biologics as targeted therapy to block an abnormal protein in a cancer cell or to attach to a specific protein on the cancer cell, flagging the cell for removal by the body's immune system.

Another rapidly developing field of immunotherapy is known as Chimeric Antigen Receptor (CAR-T) cell therapy. This technique involves collecting T cells from a patient and then changing the T cells in the laboratory so that they express a receptor which allows them to recognise the cancer cells. The modified T cells are grown in the laboratory and then injected back into the patient.

Microparticles, or exosomes, represent an exciting new class of mammalian cell product, containing a number of molecules including microRNA that can mediate inter-cellular communication. As a very new technology[8], Australia lacks the capability to develop the production processes for such particles and to produce them at scale.

There has been some fragmented and uncoordinated research infrastructure support in Australia for a range of cell approaches, including CAR-T and other T cell therapies. There is a clear need for an integrated national program of research infrastructure to provide the technical skills needed to translate novel research developments to the clinic. This capability need to includes developing scalable production processes acceptable to regulatory authorities.

5.2.3 'Omics

With new knowledge of the genetic basis of disease and rapidly declining costs of DNA sequencing, the use of patients' own genome sequence data to guide medical treatment and support translational research is becoming a reality.

5.2.4 Biobanking and population genomics

In addition to high quality national infrastructure to support 'omics, and the ability to collect, store and analyse high quality clinically useful data, high quality standardised tissue collection and banking must be addressed. A significant improvement in research effectiveness could be achieved by integrating existing tissue biobanks into collaborative networks linked to the research community. There is a need to consolidate existing efforts and create virtual networks with stable national funding. This would be targeted at the collection of samples of greatest research utility, including samples from clinical trials, rare disease cohorts and genetic syndromes, and could achieve a significant step change in managing patients with cancers of breast, colon, blood and the brain. It will also have an impact on the management of chronic debilitating diseases such as Alzheimer's and Parkinson's and inherited cardiac disease.

Population genomics enables ground breaking research into the genetic causes of disease, their population impacts and possibilities for reducing disease and improving health outcomes through risk prediction, prevention, early diagnosis and more effective and better targeted individual therapy for patients. By combining collections of de-identified genomic and phenomic information these opportunities are greatly enhanced.

5.2.5 National health and medical data capability

Research into health care and outcomes depends on large scale linked data for health and health service use. Increasing government interest, at both the state and federal levels, in linking health with non-health data will enhance capacity to investigate and address the effects of social disparities on health.

The Population Health Research Network (PHRN) was established in 2009 to support the linkage of population related administrative data. Australia has excellent population level administrative data sets. For health, these include birth and death, cancer registry, emergency department, Medicare Benefits Schedule and Pharmaceutical Benefits Scheme data and in-hospital patient statistics.

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[8] http://www.codiakbio.com/

PHRN has also supported the Secure Unified Research Environment (SURE)[9] facility which is a secure, remote-access facility for analysing linked administrative data. It gives data custodians a highly secure environment in which to make datasets available to researchers and with a high performance computing environment for data analysis.

There is a growing need in Australia for timely recognition of disease outbreaks and associated pathogens of public health concern. While there has been some population based systems development, further investment in national infrastructure linking state and federal disease control agencies with researchers and reference laboratories is highly desirable. If linked to appropriate computational power and bioinformatics expertise, this investment will greatly improve research outcomes and translation into countermeasures and public health policy.

5.2.6 Imaging

The current generation of national imaging infrastructure with existing hardware including MRI and hybrid equipment (PET/MR and PET/CT) appears to be very good. Its productivity could be greatly improved with better integration of existing infrastructure and resources across the country. The most significant gap remains new tracer development for PET analysis and, in the case of some important therapeutics, reactor-produced radioisotopes.

These tracer compounds are bioactive molecules and proteins labelled with radioactive isotopes used to track biochemical and physiological processes in vivo. Their appropriate use means that many diseases may be diagnosed much earlier and the response to treatment evaluated with better accuracy. The medical community and the operators of cyclotrons across the country have self-organised to enhance operations and share technical developments. This collaboration should be actively developed and enhanced to support the clinical translation community that uses cyclotron products for imaging. The imaging communities will need to develop common standards and approaches for translational imaging to support optimal outcomes from clinical trials.

A number of facilities already exist and provide tracers for research and clinical diagnostic imaging and the capacity to produce and develop new tracers for research needs to be increased to meet national demand.

5.3 Desirable New Capabilities

5.3.1 National collaborative approach for PET tracers and cyclotrons

There are a range of commercial and research cyclotrons in Australia. At present, coordination is based on operational excellence and reducing operating costs. For this network of cyclotrons to be more important clinically, planning and prioritisation of access to radioisotopes and tracers should be improved. From a skills perspective, providing better access for chemists and radio-chemists for developing and using PET tracers will be important over the next decade. Improved outcomes would leverage image based research and clinical translation. The key tools used by researchers and clinicians are PET and SPECT cameras and integrated imaging facilities such as PET/CT and PET/MR.

[9] http://www.saxinstitute.org.au/our-work/sure/

For clinical results to be acceptable for clinical trials, the standardisation and calibration of such facilities is absolutely crucial. Networking should involve improved access and shared knowledge of new tracers. Clinical translation organisations should be required to standardise their methods nationally to reduce duplication and enhance sharing of results.

5.3.2 Indigenous research platforms

Currently, the population and health service use of data relating to Indigenous Australians is scattered and often difficult to access. There are significant barriers to using this data as Indigenous identifiers are often missing or incomplete. For example, recent research has showed that there is no birth registration for around 18 percent of children under the age of 14 in Western Australia.

A national capability to accelerate research to improve Indigenous health should be established. The capability would consist of a centralised linkage and data clearinghouse to analyse datasets, including by Indigenous researchers, ensuring that best use is made of existing data for the Indigenous community, while respecting Indigenous needs around data collection and sharing.

This capability is further explored under Chapter 8 Understanding Cultures and Communities.

5.3.3 Bioengineering solutions for precision medicine

Building on existing capabilities, and with a focus on translating discoveries into clinical outcomes, Australia has much to gain from a continued focus on biologics and antibody technology, cell therapies and stem cell core facilities.

5.3.4 Stem cell therapies

Stem cell science has the potential to revolutionise the understanding of human developmental biology and physiology and offers discovery and technology platforms that potentially affect many fields of biomedical and clinical research. However, this is a particularly complex field with high barriers to entry for most biomedical researchers. For this reason, a national capability providing researchers with advice and access to cell lines, protocols and training should be considered. This would assist Australia to develop regenerative medicine capability to significantly improve health outcomes.

Collaboration is essential to realise the full potential of stem cell research and regenerative medicine in improving human health globally. This is particularly true in Australia where the stem cell research community is of high quality, small and geographically dispersed. Stem cell core capabilities will be critical and could include:

- automated, cGMP-compliant induced pluripotent stem cell (iPSC) capability
- patient-derived iPSC banking
- automated genome-engineering, and
- whole genome analysis and subsequent development of, and integration with, a self-learning, open, computational platform.

5.3.5 Managing and leveraging research data insights

Data systems to support the interrogation and interpretation of clinical practice and research data, creation of a strong bioinformatics capability, education of the current and next generation of clinicians to understand integration of data analysis into practice and changes to the way routine consent by all patients for ethics approved research is obtained are all critical.

A population biobank for population genomics and research into the causes, prevention and treatment of disease will provide significant national benefit. Other countries have well-established population biobank infrastructure supporting important research. The UK Biobank, for example, has samples from 500,000 people of blood, urine and saliva in secure storage for analysis, providing detailed health and lifestyle information and includes agreed follow-up and linkage to individual health records[10].

Australia has many small tissue and blood sample banks but no population biobank. New facilities for rapid and relatively low-cost whole genome sequencing would enable the scaled up processing necessary for population genomics to support research into the full spectrum of human disease.

Creating a national health and medical big data capability would enable linkage and use of large scale data encompassing the full spectrum from genome to health services and health outcomes, leveraging existing and emerging datasets. This capability would build on and substantially extend the existing PHRN infrastructure. It would enable a single, streamlined approval process, without the requiring interaction with multiple data custodians, ethics committees and data linkage units.

We need to ensure that all ‘omics data collected in research infrastructure is obtained using clinical, industry and international standards. There will be increasing need for transcriptomics, micro and non-coding RNAs, epigenomics proteomics and metabolomics data.

In order to maximise clinical utility through agreed data specifications, ‘omics data should be collected using well defined and broadly applicable clinical and industry standards. This will require alignment of research facilities with diagnostic pathology groups to develop National Association of Testing Authorities (NATA) accredited research units. National research infrastructure in all ‘omics areas should adopt international standards as they develop.

[10] http://www.ukbiobank.ac.uk/about-biobank-uk/

This table provides a snapshot of current and proposed future research infrastructure capabilities. These are examples and are not an exhaustive list.

Research Infrastructure Snapshot – Health and Medical Science		
	Existing capability elements	**Existing infrastructure**
Now	• Biological collections and biobanks • Digitisation • eResearch • Integrated biosecurity • Population Health Research Network • Translating health research	• National Computational Infrastructure • Pawsey Supercomputing Centre • Bioplatforms Australia • Population Health Research Network • Australian Microscopy and Microanalysis Research Facility • National Imaging Facility • Therapeutic Innovation Australia • Australian Nuclear Science and Technology Organisation: neutron scattering, x-ray scattering and electron microscopy • Australian Animal Health Laboratory
	Emerging trends	**Examples of potential new infrastructure**

Future	In addition to continuing existing capabilities:
	• Expand the Population Health Research Network
	• Enhanced biomolecular research
	• Enhanced imaging capability
	• Enhanced BSL4 laboratory capability
	• Develop bioengineering solutions for precision medicine
		• National health and medical big data capability, covering:
		  ○ infectious disease outbreaks
		  ○ bioinformatics skills
		  ○ Indigenous research platform
		• Coordinated tracer programs for imaging and therapy, and the associated integrated management, to effectively utilise current and future cyclotrons and reactor-based isotope production
		• Certification and expansion for Biosecurity Level 4 laboratory
		• Bioengineering solutions for precision medicine for: biologics and antibody technology, cell therapies, and stem cell core facilities

Question 15: Are the identified emerging directions and research infrastructure capabilities for Health and Medical Sciences right? Are there any missing or additional needed?

Question 16: Are there any international research infrastructure collaborations or emerging projects that Australia should engage in over the next ten years and beyond?

Question 17: Is there anything else that needs to be included or considered in the 2016 Roadmap for the Health and Medical Sciences capability area?

6 Environment and Natural Resource Management

Australia's productivity, and many of its industries, as well as the wellbeing and health of ecosystems and population depend on the environment and the ecosystem services. To ensure that development is optimised in a sustainable and effective manner, a robust, evidence based national system to understand and manage water, carbon, soil and air resources is needed. We need to continuously improve our understanding of the plants, animals and mineral resources that underpin our agricultural and resource sectors to ensure a balance between development and the environment.

The lists of capabilities presented here are neither exhaustive nor prioritised.

6.1 Emerging Directions

6.1.1 Integration

In the first wave of 'big data', research looked for patterns to drive the creation of hypotheses. This coming decade will see greater data integration through 'smart data' methods. Recent advances will see future efforts shifting from how to collect and manage data to how to support data integration, modelling and analysis to improve prediction and reduce uncertainty. Integration will include next generation infrastructure capability including large public databases, such as access to regional climate and weather models widely across the public and private sectors to increase productivity.

Big data should include the dissemination of integrated timely and harmonised data for and from both research and non-research purposes to maximise the sustainable management of our continent's 7.741 million km^2. Operational data from the Bureau of Meteorology, Geoscience Australia, and many other operational organisations will be critical inputs.

Spatio-temporal predictive modelling allows the prediction of extreme events and cumulative impacts, so informed decisions can be made and timely biological and engineering solutions can be developed. This can be applied to areas from groundwater cumulative impact modelling through to climate smart/precision agriculture.

6.1.2 Climate and water resources

Knowledge based and adaptive water management approaches at all scales, from near and deep oceans to urban to farm use, will be critical tools in Australia's efforts to achieve sustainability and benefit the economy. Key challenges for Australia over the next few decades will be climate variability, environmental change, water security and our ability to sustainably manage the competing uses of: agriculture, minerals extraction, industry, environment, and energy. In the southern half of the country, challenges include more efficient and smarter use of identified surface and groundwater resources, while not compromising vulnerable ecosystems.

In coastal areas, challenges include prevention of over exploitation of coastal aquifers and minimisation of the hazard posed by ingress of seawater intrusion and coastal inundation. In the northern half of the continent, challenges include identifying groundwater resource options to balance economic development and environmental sustainability. As an example, inland development and changing precipitation patterns could have downstream impacts on coastal or terrestrial aquaculture industries which will need to be managed in the future given the likely high future demand/appetite for fish and fish products (this is explored further in Chapter 9 National Security).

6.2 Current Capabilities and Emerging Capability Needs

Some clear gaps have emerged including: monitoring key alpine, tropical and desert ecosystems; soils (carbon, water, nutrients flow); vegetation response to changing water flows; surface and groundwater interactions with the coastal zone where there exist competing demands and increasing risks from sea level rise and climate change are most acute.

6.2.1 Atmospheric observations

Atmospheric observation capability, including modelling based on observations, continues to be a high priority. The ongoing development of a national weather, climate and earth system simulation capability, for example the Australian Community Climate and Earth System Simulator (ACCESS), including leveraging international activity, will continue to require attention.

The Marine National Facility has achieved a step change in ocean-atmosphere observations, and continued capability in atmospheric composition, dynamics and land-air fluxes, which are essential for improved weather forecasting. In addition, the current network of land-air CO_2 and water fluxes (OzFlux) that monitor greenhouse gas concentrations and land-air fluxes of water will need to be enhanced to provide integrated observations.

The ACCESS model system leverages international work by incorporating some components from the UK Met Office (the atmospheric model) and the USA (the ocean model – MOM) with Australia's land module (CABLE). Effective weather and climate predictions build preparedness and resilience to seasonal variability and climate extremes and earth system simulations enable exploration of future climate trajectories for different scenarios, provide guidance of future choices, and identify potential system tipping points so industries and the environment can best manage emerging risks.

6.2.2 Marine environment

While significant progress has been made with modelling observational and biological data, integration needs to be enhanced. To maintain Australia's world leadership in marine science, particularly in the Southern Ocean and the Antarctic, ocean observation and monitoring, blue water research and related data modelling and simulation capabilities need to be sustained.

In addition, ongoing capability building will be required to improve aquaculture, both fresh and saltwater, through integrated studies of genetics, physiology, health, aquafeeds, environments and food science to meet food demands and restock depleted recreational and commercial stocks.

This capability continues as a high priority requiring enhanced data management and integration to ensure Australian participation in international science projects.

6.2.3 Terrestrial systems

This capability continues as high priority and requires integration across data types, priority ecosystems and gaps in soil, ground water, air and the tropical and coastal zones. The emerging trend of linking terrestrial systems observational data to biological data needs to continue. Significant progress has been made in this area, but major gaps still exist.

There is a need to engage a wider range of stakeholders and end users to agree on the essential environmental variables to measure and further encourage researchers to collaborate and integrate data, models and infrastructure. Data collected on agreed long term environmental variables to sustainably manage resources and ecosystems[11] is essential. For example, long term data on the potential impact of mining, nutrient flows, climate change, urbanization and sea levels on ecosystems are required to establish viable solutions.

6.2.4 Solid earth

This capability continues as a high priority and must focus on improving efficiency in mineral extraction, water security and remote sensing. The need for Australia to continue to effectively collaborate nationally and globally to access data and analytical capability has increased for sustainable resource management and flow on benefits to the economy. The current AuScope investment provides Australian geodesists and geoscientists with a world class positioning infrastructure system that is now one of the most heavily used in the world. Extensive research to address multiple environmental challenges, including future conventional and non-conventional gas developments and data integration is being undertaken at Geoscience Australia through the Data Cube and collaborative activities between the Department of the Environment and Energy, Bureau of Meteorology, CSIRO and Geoscience Australia on Bioregional Assessments.

6.3 Desirable New Capabilities

Overall, both the targeted and enabling capabilities identified in earlier roadmaps remain a high priority as Australia's water related challenges increase**.**

There are several areas of existing national capability that should be built up, including: a more explicit emphasis on people and networks/collaboration; integration across all three elements of research capability (people, networks and infrastructure); emerging technologies in sensors and sensor networks, biological and environmental sciences and the ongoing supply of internationally competitive, high-performance computing and data infrastructure to develop new models and provide critical insights for the development of effective management solutions to climate variability and climate change.

Priority areas yet to be addressed include: access to international satellite based remote sensing data; the operationalisation of the sites that provide the calibration and validation data that underpins remote sensing products; and skilled personnel to develop algorithms and tools to fully exploit the data for the global satellite community.

Research capabilities will be critical to the deployment of technological advances to build measurement networks and platforms across the domains of water, land, and atmosphere and integrate this knowledge for use in a wide variety of domains including conservation, agriculture, mining and fisheries, including aquaculture. For example, a quantitative understanding of our groundwater resources and its interaction with surface water and ecosystems is essential as

[11] *Contemplating the future: Acting now on long term monitoring to answer 2050's questions.* D B Lindenmayer et al Austral Ecology *(2015)* 40:213-224

groundwater constitutes more than 95 per cent of Australia's fresh water[12].

New national research infrastructure requirements must be aligned with broader research priorities and directions, possibly by the development of an overarching national strategic plan for future environmental research capabilities, including infrastructure. Such a framework could be developed from existing plans, such as the *National Marine Science Plan* and *Foundations for the Future - A long term plan for Australian ecosystem science*.

6.3.1 Nationally integrated automated database

Australia requires continuing access to satellite based and proximal remote sensing to enable automated large scale collection of environmental data. This includes in situ, airborne and satellite based observations; measurement platforms; and observatory and analytical infrastructure. Sensors and sensor networks for automated observation and collection of data can provide automated monitoring in situ for agreed essential environmental variables. Gathering large amounts of essential data automatically is the most cost effective solution to data gathering needs, given gaps in observing networks have been identified across the atmosphere, soils (carbon, water and nutrients), coasts, oceans, freshwater and groundwater domains.

A national approach to sensor networks could lead to the establishment of a baseline state, and provide data on how this is changing in response to external factors, to assess the effectiveness of interventions. It will be important to utilise significant advances being made by the publicly funded research agencies and the private sector within Australia, as well as the private and public sectors internationally.

A challenge will be to find mechanisms to give researchers access to databases from a variety of sources, both public and private.

6.3.2 National model systems

Agreed national model systems, such as the ACCESS climate model, will be required for a range of Earth System Models (weather, climate, atmosphere, terrestrial biogeochemical and hydrological processes, ocean biogeochemistry, human socioeconomic systems; and biodiversity) to provide a synthesis and predictive capability for Australia's weather and climate including:

- ecosystem biodiversity and resources (air, water, carbon and nutrients)
- coasts and oceans, and
- agriculture, mining and energy resource exploration.

These national models will rely on international collaboration and so Australia must give as well as take to ensure ongoing access to globally significant models.

New capability and infrastructure are needed to enable future national water security. Surface water and groundwater research and integration need to be expanded and enhanced to manage water

[12] *The heart of the nation's water*. N Andrew quoting Prof Craig Simmons and Dr Rick Evans. Focus, Australian academy of the technological sciences and engineering (ATSE) Number 189, 2015

demands in the future. As research matures, operational components could be managed by the Bureau of Meteorology, where appropriate.

For Australia to continue to be one of the world leaders in marine research and to protect Antarctica, there is a need to utilise marine vessels and the marine fleet more efficiently, build modelling capacity across hydrodynamic and biogeochemical (oceans and coasts), examine deep oceans, coastal zones, terrestrial waters, cumulative impacts on marine ecosystems and ocean-air interactions.

6.3.3 Integrated biological facilities for plant and animal sciences

Existing facilities in plant and animal biological sciences will need to continue to support frontier technologies as they will grow in importance and play a key role in addressing barriers to agricultural yields, including adaptation and mitigation of climate change.

Future capability must include greater integration of genomic, phenomic, metabolomic and proteomic facilities to capture new scientific advances at the intersection of these areas. Data integration will be key and will require advances in bioinformatics, visualisation and software development. Advances in gene editing and in visualisation will require increased sophistication in computing and software development and access to eResearch infrastructure. Support will also be needed to continue building on existing taxonomy capability.

There is an opportunity to create nationally integrated research facilities to become ‘ecosystem observatories’. Australia has a range of experimental facilities and sites across the country including long term monitoring sites, agricultural field stations and marine or experimental aquaculture facilities. Greater coordination of these facilities would enable better utilisation of resources and support collaborative efforts for national scale modelling to, for example, increase agricultural nutritional value without additional land requirements and reduce the risk of disease in aquaculture industries.

This table provides a snapshot of the current and proposed future research infrastructure capabilities. These are examples and are not an exhaustive list.

Research Infrastructure Snapshot – Environment and Natural Resource Management		
	Existing capability elements	**Existing infrastructure**
Now	• Atmospheric observations • eResearch • Marine environment • Solid earth • Terrestrials systems	• Access to Ocean Data Network • ACCESS model • AuScope • Atlas of Living Australia • Australian Animal Health Laboratory • Australian Plant Phenomics Facility • Bioplatforms Australia • eResearch • National Computational Infrastructure • Groundwater projects • Integrated Marine Monitoring System • Marine National Facility including RV Investigator and the Icebreaker • Terrestrial Ecosystem Research Network
	Emerging trends	**Examples of potential new infrastructure**
Future	• Better integration across capability elements • eResearch enhanced • Marine expanded to include coastal zones • Solid earth improved surface and groundwater interactions • Terrestrials systems expanded to include desert, tropical and alpine regions	• National integrated automated database system • Enhancement of eResearch capabilities • Integrated observing/modelling systems and facilities • Marine vessels to support ongoing research • Integrated biological facilities for plant and animal research • Collaboration and engagement, across public, private and international domains

Question 18: Are the identified emerging directions and research infrastructure capabilities for Environment and Natural Resource Management right? Are there any missing or additional needed?

Question 19: Are there any international research infrastructure collaborations or emerging projects that Australia should engage in over the next ten years and beyond?

Question 20: Is there anything else that needs to be included or considered in the 2016 Roadmap for the Environment and Natural Resource Management capability area?

7 Advanced Physics, Chemistry, Mathematics and Materials

This capability area relies on the application of advanced physics and chemistry and includes research infrastructure for astronomy and space science, fabrication and processing, imaging and analytics, nuclear and accelerator science and defence science research fields. These capabilities strongly rely on eResearch infrastructure, particularly high performance computing and data storage and analysis.

Some areas, such as astronomy and space science, can only be fully realised and enabled through international collaborations due to the scale of infrastructure needed.

The lists of capabilities presented here are neither exhaustive nor prioritised.

7.1 Emerging Directions

7.1.1 Precision measurement

Advanced physics methods have long underpinned measurement capabilities employed in other areas. This continues to be true, with quantum enabled technologies, which are likely to become increasingly important over the next decade. For example, the interferometric techniques developed in Australia for the Grace Follow-On mission scheduled to be launched in 2017, will enable better mapping and management of Australia's water resources. The next decade will also see atom trapping methods being widely deployed for precision measurement.

7.1.2 Chemistry and high throughput processes

Chemistry is a pervasive capability encompassing biochemistry, organic, inorganic, physical chemistry and the development of hybrid materials. Australia has a world class chemistry research community that is engaged in both new materials discovery and chemical process development and understanding such as biochemical pathways.

Materials, new chemical development and the determination of chemical pathways are complex tasks that take time and require significant support. New methods of in-silico design and modelling, high throughput and combinatorial preparation and characterisation methods are emerging, shortening the time and cost of discovery. New chemistries that are bio-mimetic or integrating various chemical regimes such as hybrid materials will need new characterisation facilities that push the current limits of sensitivity and parameter detection. For example, this includes conversion chemistry which converts carbon dioxide into fuels from sunlight (photocatalysis).

7.2 Current Capabilities and Emerging Capability Needs

7.2.1 Astronomy and cosmology

Australia has consistently performed at a high level in astronomy research, discovery and impact. Broadly separated into optical and radio astronomy, each requires large scale instruments with complex and sensitive instrumentation, as well as supercomputing facilities and massive data storage. This highly specialised instrumentation and associated processes have had a track record of translation through to other areas of research and industry, as devices can be adapted for use in aerospace, medical science, defence and telecommunications applications. The most widely recognised translational benefit of astronomy is the invention of Wi-Fi, developed through CSIRO's radio astronomy research.

New astronomy facilities coming on line, such as the Giant Magellan Telescope, the Square Kilometre Array, and the already operational Australian Square Kilometre Array Pathfinder, in addition to high performance computing, will enable multi wavelength and multi messenger astronomy to be undertaken by enabling research from many different datasets. A plan is needed to enable the support of existing older infrastructure to enable wind down and repurposing while building up new infrastructure. Large scale data management capabilities to support appropriate use, reuse and discovery of data will be critical to the future of astronomy. Due to the extremely high volume of data generated from radio astronomy, the ability to collect and manipulate the data is reliant on high performance computing capability such as the Pawsey Supercomputing Centre and National Computational Infrastructure. High performance computing is discussed in more detail in Chapter 10 Underpinning Research Infrastructure.

Modern astronomy research facilities require substantial capital investment, often beyond the means of any single country. Australia currently funds access internationally based telescopes including GEMINI, Magellan and KECK. For other international research facilities, there may be opportunities to be a founding partner or co-invest once established. There is a need for a formal mechanism to determine if Australia should join international research facilities, such as the European Southern Observatory (ESO), Laser Interferometer Gravitational Wave Observatory (LIGO) or the Virgo interferometer experiment.

There is a growing interest in Australia to deepen its skills and domestic capabilities in gravitational wave observations. This capability could serve both domestic and international research where there is a need to improve detection and triangulation of cosmic gravitational waves in consort with existing facilities overseas.

7.2.2 Fabrication and processing

Australia has invested well in the network of nano and micro fabrication facilities through the Australian National Fabrication Facility, leading to a strong collaborative network capability that operates at a very high level.

A distinguishing feature of the fabrication landscape has been the breadth of development, ranging from polymeric and organic materials to inorganic semiconductors. Investment in generic and materials specific processing capabilities has proven a successful strategy for encouraging the widest research scope. This has created a capability environment where future trends in fabrication include the development of instrumentation allowing for hybrid materials platforms and the creation of integrated devices that incorporate photonic and biological chemical functionalities.

While the investment in integrated fabrication and process monitoring has enabled device and material prototyping, a focus on packaging across multiple length scales is required to enable nano and micro device technologies to interface with real world systems. Development of a national translational capability to bridge the gap between the scientific understanding of new materials and the fabrication of prototype devices through to pre-commercial testing requires the ability to scale up production to yield sufficient quantities of advanced materials or devices for development and trials.

There is a growing need to enhance the capability, particularly around increasing packaging, scale up, and integration facilities. This will ensure that reliable and productive translation into emerging commercial opportunities can be realised.

Australia has made significant investment in quantum research capability and is a leader in quantum computing, which has resulted in world class research outcomes. This investment has provided a competitive advantage for future quantum research.

The characterisation and fabrication capabilities experience some overlap, but this is unavoidable due to the research infrastructure requirement of the process quality monitoring workflow. A national user access scheme has been important to promote the advanced, often unique facilities.

7.2.3 Imaging and analytics

Australia is well served by facilities enabling characterisation both domestically and internationally. Characterisation and imaging capabilities have developed parallel infrastructure, although these are now converging around shared technology, application, data management, technical skill sets and multi-modal data integration. Most integration has occurred in the biological sciences, where the two capabilities have the greatest overlap. While characterisation facilities are comprehensive, a more strategic and networked approach is the logical next step, including between characterisation and imaging to increase the potential for digital processing capacity.

The translation of data integration products and even new instrumentation is identified as an area that might be enhanced in a renewed imaging and analytics capability. Currently there is limited capacity to provide accredited and verified services to support this capability at both a data acquisition and reagent supply levels. Specific issues relating to the certifiable quality of the data acquired (owing to laboratory and process accreditation) need to be remedied to allow translational and industry readiness.

The developing imaging and analytical requirements in Australia are stretching current modalities to afford additional dimensional information. Measurements are increasingly requiring multidimensional and multimodal tools, requiring integration of complex analysis techniques. All of these developments require an ever expanding range of specialised skills in the associated support workforce, and need to be recorded and transferred to ensure continuity. In many instances no commercial instrument integrates the key modalities desired. User access schemes ensure a high value return on investment in highly specialised facilities.

7.2.4 Accelerator science

This capability is generally meeting demand within existing facilities and with maintenance should continue to meet the needs of most communities. The accelerator capability is distributed and encompasses a range of facilities including the Australian Synchrotron, medical cyclotrons and the heavy-ion facility.

Due to the level of investment required to achieve significant capability in emerging areas such as rare isotope accelerators, exploring international consortia may be the best path for Australian researchers to expand into these areas. Access to large scale international accelerators is already particularly critical for the particle physics community in Australia where experimental programs are reliant on facilities overseas. As with neutron science, some access to these facilities should be considered as part of an integrated infrastructure solution.

7.3 Desirable New Capabilities

7.3.1 Precision measurement

New precision measurement capabilities will evolve over the next decade. Important in assisting this development is the maintenance and extension of the capabilities that exist, for example in the National Measurement Institute to reference these techniques to international standards. Overlaps will also occur in defence science capabilities, geo-sensing and marine sensing.

7.3.2 Chemistry and high throughput processes

There are facilities and chemical libraries that are embedded in universities and government laboratories that support the chemistry community through, for example, providing access to robotic and automated equipment allowing high throughput processes. Recognition, availability and access to these facilities could be improved with a national strategic approach, as while some are open access, many are only available for local use.

7.3.3 Space science

The entrance cost to make Australia a space ready nation is significant. Nonetheless, it is important to consider the need to develop a level of preparedness around certain technical capabilities in the space science area. Several existing capabilities, particularly fabrication and astronomy, could contribute productively to the development of remote sensing and resource mapping instruments, whether space-borne or near-Earth. The second possibility for growing future capability could focus on launch facilities.

This table provides a snapshot of the current and proposed future research infrastructure capabilities. These are examples and are not an exhaustive list.

Research Infrastructure Snapshot – Advanced Physics, Chemistry, Mathematics and Materials		
	Existing capability elements	**Existing infrastructure**
Now	• Astronomy • Characterisation • Fabrication • Sustainable Energy	• Astronomy Australia Limited • Australian Astronomical Observatory • Australian Microscopy and Microanalysis Research Facility • Australian National Fabrication Facility • Australian National Telescope Facility • Australian Nuclear Science and Technology Organisation – neutron scattering, beam instruments, imaging and isotope production • Centre for Accelerator Science • Australian Synchrotron • Australian Plasma Fusion Research Facility • Biofuels • Heavy Ion Accelerator • National Imaging Facility
	Emerging trends	**Examples of potential new infrastructure**
Future	In addition to continuing existing capabilities: • Enhance fabrication focus on packaging and integration capabilities • Convergence of imaging and characterisation capabilities	• Development of a precision measurement capability • National chemistry capability • Space science capability

Question 21: Are the identified emerging directions and research infrastructure capabilities for Advanced Physics, Chemistry, Mathematics and Materials right? Are there any missing or additional needed?

Question 22: Are there any international research infrastructure collaborations or emerging projects that Australia should engage in over the next ten years and beyond?

Question 23: Is there anything else that needs to be included or considered in the 2016 Roadmap for the Advanced Physics, Chemistry, Mathematics and Materials capability area?

8 Understanding Cultures and Communities

Understanding Cultures and Communities (UCC) is exactly about that: understanding human, cultural and societal processes, trends and interactions. This area of research is critical to making sense of our world and the role that people, cultures and communities play in shaping it. By its very definition, UCC is a broad and diverse research area, covering the domains traditionally identified under the humanities, arts and social sciences (HASS), and consequentially has broad and diverse research infrastructure needs.

The lists of capabilities presented here are neither exhaustive nor prioritised.

8.1 Emerging directions

8.1.1 Innovation and translation

Innovation and translation of research has been a major trend in the past decade, with the Australian Government increasing focus on innovation through its National Innovation and Science Agenda and with universities increasingly interested in innovation outcomes and research translation. There are numerous ways that advances in knowledge from UCC research can innovate to create better solutions to major unresolved problems of global significance. Innovation can involve developing new programs, interventions or the adoption of unique findings from research activities to activities of national benefit.

There are important ethical and community dimensions to the proper use of data in this domain, and therefore custodianship and curation needs to take account of community and cultural sensitivities and associated rights.

8.1.2 Digital humanities and digital repatriation

The use of massive datasets and sophisticated digital tools, techniques and technologies has become increasingly important to humanities research. Digital humanities research and its related infrastructure is at the forefront of capturing born-digital cultural data, especially cultural content developed through digital content generation and social media. The National Library of Australia's Trove has emerged as the nation's core digital humanities research infrastructure, enabling a paradigm shift for humanities researchers, providing a powerful platform to build sophisticated tools and techniques.

Digital repatriation is an issue of increasing interest and importance in the digital humanities, particularly as datasets containing data on communities whose collection was not based on free and informed consent, are digitised and made available freely online. However, digital repatriation also provides an opportunity for individuals and communities to regain control and management of data that was collected in the past. Digital repatriation exists as both a technical and ethical issue.

The digital humanities, as a discipline, have a heavy reliance on digitisation technologies that are explored in Chapter 10 Underpinning Research Infrastructure.

8.1.3 Future role of cultural and data institutions

National and state cultural collecting institutions are a vital set of national research infrastructure to researchers. They provide access to historical documents, cultural artefacts, images, sound recordings and art collections, as well as the vast data holdings of the state and federal governments. Newly emerging digital tools created by these institutions are becoming indispensable. Maintenance, preservation and ready access to these collections is a key emerging concern to ensure that the use, value and potential of these national assets is maximised.

Research infrastructure-like activities currently undertaken at national cultural institutions need to be supported and recognised as core national infrastructure, as important as any other research infrastructure holding, and just as irreplaceable. This includes consideration on the research impact of changes to the development, curation and availability of data and services, and the flow-on impact these decisions may have on longitudinal and long-term research and research infrastructure activities.

8.2 Current Capabilities and Emerging Capability Needs

8.2.1 Urban settlements

The capability to enable the collection and integration of datasets covering the range of human activities by those working, investing and living in urban areas is still required, with governments at all levels demonstrating renewed policy focus on cities and sustainability. eResearch tools need to be augmented to link environmental and geoscientific datasets to form a holistic picture of urban settlements. The integration of societal observation data, along with environmental observational data, will enable a new paradigm of urban research, enabling a more fulsome research effort on the design, operation, sustainability and liveability of urban environments and the impact that changes are having.

8.2.2 National and state institutions

The ability to compare, contrast, manipulate, link and integrate the holdings of national and state institutions, particularly via digital technologies, enables researchers, regardless of their physical location, to conduct research on national cultural holdings, which maximises access and utilisation of these holdings. Access to historical documents, images, cultural artefacts, art collections and the vast data holdings of governments is core to UCC. Maintenance of these holdings is an increasing challenge that needs to be addressed.

The capability of national cultural and data institutions' research infrastructure provision can be enhanced through integration and increased harmonisation of data standards, and the provision of tools and techniques to increase data interoperability.

8.3 Desirable New Capabilities

8.3.1 National digital humanities capability

The national digital humanities capability is required to make both old and new data discoverable and usable and to extract greater value from existing collections that are as varied as statistical data, manuscripts, documents, artefacts and audio-visual recordings, as well as collating and leveraging the vast array of born-digital content. This capability will draw together, leverage and enhance existing investments in Trove, the Humanities National Infrastructure, the Australian Data Archive, and the Australian Institute of Aboriginal and Torres Strait Islander Studies (AIATSIS) digitised collections, amongst others, to integrate and support national digital humanities research.

8.3.2 Community managed cultures and communities research infrastructure capability

A community managed cultures and communities research infrastructure capability is required to ensure that data collected on the nation's culture and communities is managed and utilised ethically within a framework of community consent and control, ensuring full community awareness and, where desirable, participation. The study of cultures and communities is an area of continued importance – it tells the story of identity, heritage, and the shared journey of all members of Australian society.

This capability will include a secure online system to deposit, manage and curate culturally sensitive data, including digital repatriated data, based on the system and procedures established by Aboriginal and Torres Strait Islander Data Archive (ATSIDA), and a community controlled permissions system, based on the system being developed by National Centre for Indigenous Genomics, to allow communities and individuals to exercise fine-grained consent and control over their data. Of equal importance will be agreement and harmonisation of policy and procedures, including best practice guides and appropriate governance, for gathering, linking, sharing and repatriating cultural and community data, based on practices established by ATSIDA and AIATSIS.

8.3.3 National network for social and behavioural science innovation

There are many untapped opportunities for commercialisation and industry partnerships in the social and behavioural sciences and many researchers need better infrastructure support to enable an idea or program to progress from innovation through to public benefit and potentially to commercial outcomes.

The establishment of a national network for social and behavioural science innovation would create the research infrastructure necessary to build a translational research capacity within the behavioural and social sciences. The network would create the much needed infrastructure to promote the development, evaluation, and dissemination of innovative solutions to major unresolved social and community problems of global significance. This capability will create research infrastructure that enables cutting edge research to be conducted to place Australia at the forefront globally of population based social innovation and behavioural change.

8.3.4 Materials conservation

One of the greatest challenges facing collecting institutions is not only the conservation of the material for which they are responsible, but developing and sharing information about good conservation practice. Much conservation practice remains unnecessarily involved, labour intensive and unsustainable. Such a capability would leverage and integrate existing materials capability developed through NCRIS and other investments to ensure their applicability for adoption to materials conservation. A process also needs to be undertaken to identify gaps in national materials conservation capabilities, and how they can be filled by domestic or international capability.

This table provides a snapshot of the current and proposed future research infrastructure capabilities. These are examples and are not an exhaustive list.

Research Infrastructure Snapshot – Understanding Cultures and Communities		
	Existing capability elements	**Existing infrastructure**
Now	• Urban settlements • Cultures and communities • Characterisation • Digitisation • eResearch	• Australian Urban Research Infrastructure Network • Australian Data Archive, including the ATSIDA* • Humanities National Infrastructure • Investments by national institutions* • National Centre for Indigenous Genomics* • eResearch
	Emerging trends	**Examples of potential new infrastructure**
Future	In addition to continuing existing capabilities: • eResearch – improved linkage of environmental and societal data • Community managed cultures and communities research infrastructure	• Enhancement of eResearch capabilities • Materials conservation • National network for social and behavioural science innovation • National digital humanities capability

*Project not currently supported by national research infrastructure programs

Question 24: Are the identified emerging directions and research infrastructure capabilities for Understanding Cultures and Communities right? Are there any missing or additional needed?

Question 25: Are there any international research infrastructure collaborations or emerging projects that Australia should engage in over the next ten years and beyond?

Question 26: Is there anything else that needs to be included or considered in the 2016 Roadmap for the Understanding Cultures and Communities capability area?

9 National Security

The National Security capability area addresses threats and risks to domestic security from invasive diseases, pests and pathogens, cyber security and crime. It is important to understand our place in the region and the world and to strengthen our national security infrastructure, especially digital systems and transformational technologies. In this chapter, the focus is supporting non-defence national security, and greater integration and access between defence and non-defence related research infrastructure capability, to ensure appropriate security processes are in place.

The lists of capabilities presented here are neither exhaustive nor prioritised.

9.1 Emerging Directions

Given the broad nature of the National Security capability area a number of emerging research areas were identified that may have national research infrastructure capability requirements.

9.1.1 Biosecurity

Emerging directions include both technological developments and disease trends. In terms of technology it is difficult to predict what will happen and developments over the last few years indicate that change occurs in “jumps” rather than incrementally. There are several emerging trends to take note of. Endemic livestock diseases biosecurity has the potential to impact public health and export markets. Exotic animal diseases and high risk zoonoses biosecurity, plant biosecurity and aquaculture and fisheries biosecurity are also significant areas for focus. Examples of disease trends include rapid global spread of high risk zoonotic diseases such as SARS and highly pathogenic avian influenza and animal diseases such as lumpy skin disease and African swine fever.

9.1.2 Cyber security

The cyber landscape is characterised by a number of risks and opportunities including accelerated global adoption of, and reliance on, cyber technology; ongoing emergence of new cyber concepts and capabilities with cloud services, and mobile capability increasing in functionality, diversity and market penetration; an emerging explosion of new cyber-physical network-enabled devices entering the market such as the internet of things with potentially very poor cyber security; increased interconnectivity and interdependence; and increased cyber security risk in the ICT hardware supply chain.

The number and diversity of cyber threats and attacks is increasing, as the internet provides global reach to individuals, organised groups and state based individuals and groups to undertake malicious activities. The resultant effect is that we have an increasing reliance on cyber space coupled with a rapidly increasing uncertainty in the cyber security of our devices, networks and systems, and in our ability to ensure cyber resilience at a national level.

9.2 Current Capabilities and Emerging Capability Needs

9.2.1 Biosecurity

Australia has a significant capacity to address biosecurity. However, coordination of plant and aquaculture capabilities lags behind animal biosecurity. Biosecurity measures to assist in prevention of bioterrorism are important. The required research capability would be further strengthened if national biosecurity research plans encompassing the various elements of exotic and endemic animal, aquaculture and fisheries and plant sectors including weed and invasive animal and marine pathogens are developed. The capability expert group considers that current infrastructure does not meet the minimum requirements for national resilience to respond to biosecurity risks.

9.2.2 Cyber security

There are major cyber research capabilities across government, industry and academia that could be utilised and integrated into any national research capability. However the existing cyber security research capability is fragmented, subscale, lacking in diversity, does not support robust, extensive collaboration and does not provide for bona fide research, development and testing in ground truth representative environments, using common representative data sets. This may be partially addressed by the industry led Cyber Security Growth Centre announced under National Innovation and Science Agenda. The Centre will have responsibility for coordination of research and innovation activities, leading to market growth.

The cyber national infrastructure will need to be relevant and responsive to the ever changing cyber challenge. As such it needs to be resilient, highly scalable, readily accessible at all times (‘always on’), easy to use and flexible (including the ability to stand up and dismantle network topologies). It needs to encompass both virtual and physical environments and be able to represent the diverse nature of cyber technologies and systems. Ideally the infrastructure would be a federated architecture that would have new capability but would include existing infrastructure available across the research community.

9.2.3 Water security

The last decade has seen a significant focus on understanding the properties of deep aquifers and aquitards and the interconnection between surface and groundwater in Australia. This is in part due to several factors that include: mining, the exploitation of conventional and non-conventional gas sources; the need to find new water supplies for agriculture, industry, and communities; exploring the efficacy and safety of aquifer recharge; and the need to find appropriate sites for CO_2 sequestration. However, defining the geological and hydrological properties of deep aquifers and their degree of isolation from other resources through aquitards remains a scientific challenge as does the full understanding of the connectivity between surface and shallow and deep aquifers. The ability to measure stable and radioactive isotopes under Australian conditions in water show considerable promise. These techniques are required to determine the residence time and age of water resources to support effective models that can determine sustainable utilisation of these critical resources.

A number of these areas are discussed in more detail in Chapter 6 Environment and Natural Resource Management.

9.3 Desirable New Capabilities

9.3.1 Biosecurity

Australia must be able to diagnose and control any exotic animal, plant or aquatic animal disease or high risk zoonosis incursion to ensure timeliness of testing and selection or development of vaccines appropriate to Australian conditions. Australia cannot rely on overseas research and must maintain its own capacity in biosecurity across all sectors as perspectives on the importance of diseases varies between countries.

There is a clear need to improve Australia's capacity in terms of research to support biosecurity in both plant health and aquaculture. A network approach would enable sharing of data and the interconnectivity of facilities to improve real time communication. Establishment of a virtual laboratory network could allow sharing of large data and reduce the need for each individual institution to be capable in every field. There is also a need to increase capability in veterinary, aquaculture and plant virology and bacteriology, veterinary parasitology and plant nematology, epidemiology and aquaculture and plant pathology in general, as these sectors have experienced downturns in key capabilities and skills.

Biocontainment facilities are imperative infrastructure as Australia cannot rely on overseas research and must maintain its own biosecurity capacity. Existing national facilities are ageing and currently do not meet minimum regulatory requirements. This creates a high risk of the facilities not being operable in the future. In addition, more extensive biocontainment facilities (laboratory and aquaria) need to be provided for aquatic and fisheries exotic disease and emerging pathogens. Facilities for endemic disease research in various jurisdictions and universities exist but with limited national coordination. The lack of Physical Containment Level 3 laboratories and greenhouses for exotic plant disease research is also a serious deficiency.

9.3.2 Cyber security

Currently there are elements of subscale cyber research capabilities across government, industry and academia. There is a requirement to develop these significantly so that they could be utilised and integrated into a national capability. The national capability would comprise high performing multidisciplinary, problem focussed research teams and the ability to transition the research outcomes to products. The infrastructure will be a key enabler for delivering cyber research impact by providing a base for researchers to collaborate with each other and end users on the key emerging challenges in cyber security. In particular, expanding cyber security beyond protecting endpoints to one of protecting a system, network and mission is an emerging area that provides opportunity for Australia.

Finally, use of the infrastructure to help nurture and grow cyber security talent is a critical function that should not be overlooked.

9.3.3 Water security

This area has been substantively covered in Chapter 6 Environment and Natural Resource Management. It is important to recognise that water security will remain a critical element requiring ongoing capability development in its own right.

This table provides a snapshot of the current and proposed future research infrastructure capabilities. These are examples and are not an exhaustive list.

<table>
<tr><th colspan="3">Research Infrastructure Snapshot – National Security</th></tr>
<tr><th></th><th>Existing capability elements</th><th>Existing infrastructure</th></tr>
<tr><td>Now</td><td>• Biosecurity
• Cyber security
• Energy security
• Water security</td><td>• Australian Animal Health Laboratory
• Australian Phenomics Network
• Australian Plant Phenomics Facility
• Bioplatforms Australia</td></tr>
<tr><th></th><th>Emerging trends</th><th>Examples of potential new infrastructure</th></tr>
<tr><td>Future</td><td>In addition to continuing existing capabilities:
• Enhance biosecurity capabilities
• Ensure cyber resilience at a national level</td><td>• Improved biocontainment facilities (BCL3 and BCL4)
• Integrate laboratory facilities across Australia, including an interconnected network
• Exploring cyber security beyond protecting endpoints to one of protecting a system</td></tr>
</table>

Question 27: Are the identified emerging directions and research infrastructure capabilities for National Security right? Are there any missing or additional needed?

Question 28: Are there any international research infrastructure collaborations or emerging projects that Australia should engage in over the next ten years and beyond?

Question 29: Is there anything else that needs to be included or considered in the 2016 Roadmap for the National Security capability area?

10 Underpinning Research Infrastructure

There are a number of areas that can be classified as 'Underpinning Research Infrastructure' which, as the name suggests, relates to infrastructure that underpins broad areas of research or in some cases all research. For the purposes of the Issues Paper, these include:

- High Performance Computing (HPC)
- High capacity networks
- Trusted communication (access and authentication)
- Neutron and x-ray scattering
- Geospatial systems
- Digitisation

The lists of capabilities presented here are neither exhaustive nor prioritised.

10.1 Emerging directions

Underpinning research infrastructure has a broad base of users and provides a critical foundational component for many other research infrastructure areas of the 2016 Roadmap.

10.1.1 eResearch infrastructure

'Underpinning' eResearch infrastructure – high performance computing, high capacity networks and access and authentication – is creating new research methods and enabling collaboration that allows researchers to address today's big challenges. Researchers are increasingly depending on eResearch infrastructure and demand is continuously growing. It is essential that Australia continues to build on existing investments and optimises future investment strategies to ensure that researchers have access to the tools they need for cross-disciplinary and collaborative problem solving, the platforms to deploy research findings and the mechanisms that support the rapid diffusion of ideas.

10.1.2 Geospatial systems

Advances in technology, including the advent of remote sensing such as imagery and other forms of data from planes, satellites and Global Positioning Systems, as well as high performance computing and software means that there continue to be fundamental advances made in relation to geospatial capabilities.

10.1.3 Digitisation

A digitisation infrastructure capability, covering a range of research areas, 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 digital form. While individual institutions are working to develop digitised collections, it is a slow process that would benefit from national coordination and funding.

Access to digital records allows researchers to gather information easily and respond rapidly to research questions and vital scenarios and enables cross-disciplinary research. Further, access to digitised and connected collections offers many time and cost benefits for researchers, leading to significant productivity gains.

10.2 Current Capability and Emerging Capability Needs

10.2.1 High performance computing

Australia currently has two Tier 1 HPC facilities that are available to researchers. This capacity has been sufficient up to this point, but the facilities and their users have indicated that computing power will need to be increased soon to meet both compute and data storage requirements. Both facilities have significant supporting infrastructure in place, in terms of both physical infrastructure and expert staff. Australia also has a number of Tier 2 facilities located across the country.

10.2.2 High capacity networks

Australia has a research and education data network that services most of the country. As would be expected for a country of Australia's size, the network does not reach all of the population and there are areas where users cannot get access. Overall, though, its current reach and capacity are serving the majority of researchers well. There are difficulties associated with industry users gaining access to the network. There are valid reasons for these difficulties, but access remains an issue.

10.2.3 Access and authentication

Australia has a robust access broker, which allows researchers to collaborate more easily across different institutions. The service provided serves researchers' needs within Australia well. Additional international access would be beneficial to encourage greater collaboration.

10.2.4 Neutron and x-ray scattering

In these important fields of characterisation there is an ongoing requirement for new neutron beam facilities and beamlines utilising the Australian Synchrotron. New application and existing capacity could be expanded at these facilities. International facilities have complementary capabilities and therefore international access schemes remain important.

Australia needs to maintain a domestic presence in nuclear science and applications as a matter of sovereignty and national security.

Australia has one national synchrotron – the Australian Synchrotron. Currently the Australian Synchrotron operates world-leading capabilities in *Small Angle X-ray Scattering* and *X-ray Fluorescence Microscopy*, with potential emerging world-leading capability in *Microbeam Radiation Therapy* and *Biomedical X-ray Imaging*.

There is substantial over-subscription for existing neutron scattering facilities at the OPAL reactor and access to beamlines at the Australian Synchrotron with demand typically between 150-200 per cent of availability. Advances in technology have reduced experiment times and supported high throughput; however enhanced capabilities would leverage existing investments.

10.2.5 Geospatial systems

Geospatial data and data models are well developed and are used by a number of disciplines. Current capabilities that use geospatial data include projects such as National Positioning Infrastructure and the Australian Data Cube.

In terms of data management, geospatial data tends to require large storage volumes and fast processors and this is especially the case for remotely sensed data. This is served through eResearch infrastructure but growing use and demand will mean that reliance will grow and the eResearch capability must grow with it.

10.2.6 Digitisation

While individual institutions are working to develop digitised collections, it is a slow process that would benefit from national coordination and funding.

10.3 Desirable New Capabilities

10.3.1 High performance computing

Researchers are increasingly gathering and utilising digital data methods that require the use of coordinated HPC. The demand is growing for both peak (Tier 1) HPC and shoulder (Tier 2) computing. For the purposes of this Issues Paper, Tier 1 facilities are described as generally having the capacity to support multiple research communities, while Tier 2 facilities are more focussed on a particular research community or are developed for the primary purpose of serving a single institution and associated researchers through collaboration.

The HPC services required by researchers include computational simulation, data modelling and analysis, integration of complex model outputs with large datasets and throughput processing for high-volume data-producing instruments. It is clear that Australia requires HPC capacity at both the Tier 1 and Tier 2 scale to meet the existing and growing needs of the country's researchers and to meet the commitments to international research endeavours such as the Square Kilometre Array project and climate system science.

Australia's Tier 1 facilities, which are currently managed, operated and funded separately, need to be upgraded at regular intervals to maintain a competitive edge globally, and to ensure that Australia's researchers have adequate HPC capacity into the future. These two facilities should be upgraded in a planned, alternating fashion, meaning that the country will always have at least one facility operating at full capacity, even when the other is undergoing significant upgrades.

To maintain a nationally coordinated Tier 1 HPC capability consideration must be given to national governance arrangements supported by a four year capital cycle. This may include greater integration which could yield greater coherence and connectivity as well as enable specialist expertise to be developed in a systemic way.

10.3.2 High capacity networks

High capacity network connectivity is critical to Australian research. Securing the future of Australia's research and education network infrastructure, the Australian Research and Education Network (AREN), is essential.

Australia's research network should be enhanced and expanded to reach more researchers. This should be done after carefully identifying the areas where the network will have the most strategic impact for research and for research and industry collaboration. Enhancements of the existing backbone should be considered, especially to capital cities not already connected to the n* 100G DWDM backbone as a matter of equity to researchers located in these cities. International connectivity shows a strong bandwidth bias (10 and 40 Gbps) to North America with a relatively narrow (2.5 Gbps) connection to Singapore as Australia's Asian gateway. Given the importance of Asia, and particularly China, as research partners with large data generation capacity, an assessment of projected international data transfers over the next decade would be worthwhile.

Consideration should be given to extending the network into regional areas where commercial services are not available and not likely to expand into these areas. Not only are there planned research facilities in remote areas, but Australians in regional areas generate increasing amounts of data of potential interest to researchers such as precision agriculture and resource management. Without appropriate network access the value of this data will not be fully exploited.

10.3.3 Access and authentication

The facilitation of trusted electronic communications and collaboration between education and research institutions both locally and internationally is a vital part of the Australian research infrastructure landscape. Australia's access and authentication infrastructure should be extended further to provide additional access to international researchers, where possible. Research is becoming more and more international, and allowing collaborating overseas researchers to access Australia's network – with the appropriate authentication and controls – will make international collaborations much easier.

10.3.4 Neutron and x-ray scattering

Continued development of new modes of automated control and remote access systems will be of value to engage larger numbers of researchers and students at the Australian Synchrotron. New mechanisms of eResearch including multi-site, virtual participation in experiments will be of benefit to national and international collaboration.

The Australian Synchrotron supports international access to many international synchrotron facilities to fill national capability gaps and to develop skills. Access to synchrotrons internationally is seen as complementary to access to the Australian Synchrotron. Appropriate contribution to these international facilities might include Australian–built equipment, such as detectors, hosted on foreign beamlines.

10.3.5 Geospatial systems

Enhanced geospatial systems, including both physical and eResearch infrastructure, are needed to improve accuracy and time resolution for the large parts of the private sector, government and research sectors which rely on accurate, timely and available spatial data to support their core operations.

New infrastructure investment should build on and leverage existing capability and Australia's unique geographic position to participate in global data acquisition programs, algorithm and technology development and for Australia to become a global leader in the global positioning industry.

10.3.6 Digitisation

Digitisation should focus on building collections of national or global significance. The resulting benefits of increased access and a greater ability to collaborate would be significant. The level of digitisation will vary by subject area – from simple metadata and 2D images through to genetic analysis, structural analysis and 3D images, just to name a few examples – but the basic concept and utilisation are similar.

Preservation is another area in which digitisation is particularly important. Many samples and collections degrade over time, and if they are not stored in digital form they will be lost forever. Although digitisation can never perfectly replace original items, it should be seen as an important risk management strategy to help ensure that important information is retained.

Having a national digitisation capability would enable specialised support for the digitisation process and thereby help it to proceed more quickly. Without this specialist knowledge, digitisation is likely to still occur, but much more slowly. Where new data is being collected, thought should be given to a digital first strategy, in which data is recorded digitally right from the beginning, wherever possible.

This table provides a snapshot of the current and proposed future research infrastructure capabilities. These are examples and are not an exhaustive list.

Research Infrastructure Snapshot – Underpinning Research Infrastructure		
	Existing capability elements	**Existing infrastructure**
Now	• Geospatial systems • High performance computing • Networks • Research access and user authentication • Reactor and accelerator technologies	• National Computational Infrastructure • Pawsey Supercomputing Centre • AuScope • Australian Synchrotron • OPAL Reactor • Australian Centre for Neutron Scattering • Australian Access Federation • Australia's Academic and Research Network (AARNet). • High capacity broadband network connecting Australian universities and research institutions • National Positioning Infrastructure
	Emerging trends	**Examples of potential new infrastructure**
Future	In addition to continuing existing capabilities: • Establishment of a national digitisation capability • Increasing importance of imaging and visualisation technologies	• Enhancement of the Australian Synchrotron and neutron scattering facilities • Upgraded high performance computing infrastructure and coordination • Maintain and operate broadband networks and extend networks, where viable and appropriate • Researcher access and authentication services extended internationally • National digitisation infrastructure • Geospatial data collection

Question 30: Are the identified emerging directions and research infrastructure capabilities for Underpinning Research Infrastructure right? Are there any missing or additional needed?

Question 31: Are there any international research infrastructure collaborations or emerging projects that Australia should engage in over the next ten years and beyond?

Question 32: Is there anything else that needs to be included or considered in the 2016 Roadmap for the Underpinning Research Infrastructure capability area?

11 Data for Research and Discoverability

"Data is central to all research….For Australia to increase productivity and address grand challenges over the coming decades, it will require a national research capability that can deliver competitive advantage in a data-rich future".[13]

The lists of capabilities presented here are neither exhaustive nor prioritised.

11.1 Emerging Directions

In terms of established infrastructure, the demands for computation and connectivity capabilities that have existed for decades continue unabated, with an increasing number of researchers taking advantage of them. An increasing and prominent trend concerns the rising dependence of research on digital data at new scales, and a variety of data not previously addressed. Data growth both expands demands on existing infrastructure and creates requirements for new infrastructure.

11.2 Current Capabilities and Emerging Capability Needs

As a result of national and institutional investment over a number of years, Australia has a world leading research data system that should be built upon and developed to maintain its current competitive edge. This system has transformed the research data environment through the provision of national capability that delivers across the research ecosystem.

11.2.1 Better managed research data

National capability investments have enabled the development and delivery of services and infrastructure to ensure that data is managed, connected, discoverable and reusable making Australia's research data assets more valuable for researchers, research institutions and the nation.

11.2.2 National research data storage infrastructure

Australia now has cost-effective, scaled up, shared research data storage services that are aimed at improving research collaboration through the storage and provision of access to research data collections of national significance.

11.2.3 Research cloud populated with digital tools and virtual laboratories

Australia's national cloud infrastructure and virtual laboratories support researchers to connect and collaborate through a distributed research cloud which enables researchers to manipulate and handle research data from a distance or in collaborations with other researchers through the availability of advanced research tools, research cloud capacity and virtual research laboratories.

These capabilities have been developed and implemented as collaborative and coordinated efforts with other aspects of Underpinning Research Infrastructure, described above.

[13] *https://docs.education.gov.au/system/files/doc/other/the_australian_research_data_infrastructure_strategy.pdf*

11.3 Desirable New Capabilities

Notwithstanding Australia's global leadership in data infrastructure, this is an emerging area and Australia needs to consolidate the gains of the past decade and create a more integrated, coherent and reliable platform to deal with data-intensive, cross-disciplinary and global collaborative research.

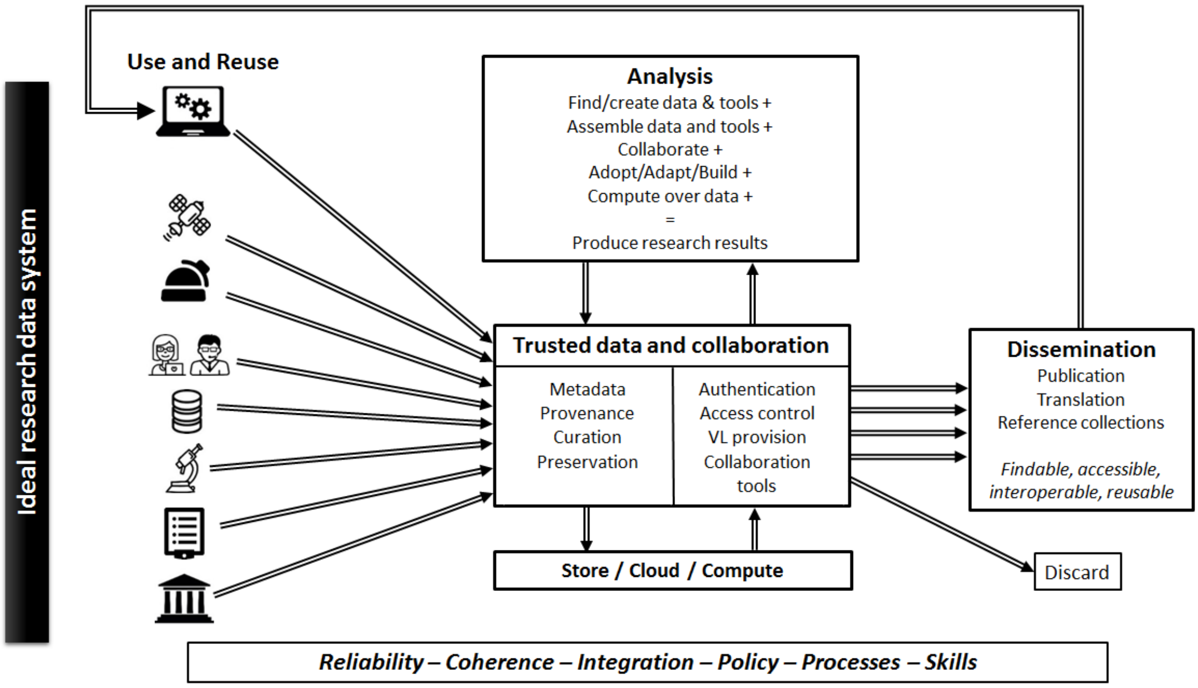
Australia's future research data capability should be informed by, utilise, integrate and build on existing investments. Research data infrastructure should support the development of collaboration environments using trusted data throughout and beyond the life of a research project, from data capture through to simulation and modelling and to dissemination, and including data storage and management, cloud services and associated expertise and capability building.

Globally, data is rapidly becoming an important research output in its own right and so a research data output needs to be as reliable and trusted as a research paper. In order to achieve this, Australia needs the infrastructure, processes and policies that will ensure that all research data outputs are reliable, able to be reproduced and able to provide a sounder basis for further research and improved translation outcomes. This infrastructure would be comparable to and be able to leverage international opportunities such as the European Open Science Cloud and other similar global initiatives.

A range of national services will be needed to support the future of data-intensive research, including cloud provision of collaboration environments, computation and storage, reliable data and provenance capture, trusted data repositories, virtual laboratory support, publishing of research outputs and the federation of data, including physically dispersed nationally significant reference collections.

Australia's data system should focus on partnerships with high performance computing facilities, research capabilities, disciplines (especially the national Science and Research Priorities), institutions, global collaborators, the public sector and industry. This focus would leverage investments and allow researchers to be innovative and address national and globally significant challenges. It would also optimise reliability and interoperability, achieve reproducibility of research results and encourage engagement with industry.

This diagram illustrates a transformed environment where data and tools are provided reliably to researchers, and then the outputs of research – the publications, data and methods – are available in an integrated, reproducible form.



This table provides a snapshot of the current and proposed future research infrastructure capabilities. These are examples and are not an exhaustive list.

Research Infrastructure Snapshot – Data for Research and Discoverability		
	Existing capability elements	**Existing infrastructure**
Now	• Software, tools and collaboration resources • Research data storage • Research data management	• National eResearch Collaboration Tools and Resources • Research Data Services-storage infrastructure and services supporting collaborative access to research data assets of national significance • Australian National Data Service-enabling research data to be findable, accessible, interoperable and reusable
	Emerging trends	**Examples of potential new infrastructure**
Future	In addition to continuing existing capabilities: • Integrated research data solutions	• An integrated Australian research data system, including cloud provision of collaboration environments, computation and storage, reliable data and provenance capture, trusted data repositories, virtual laboratory support, publishing of research outputs and the federation of data, including physically dispersed nationally significant reference collections

Question 33: **Are the identified emerging directions and research infrastructure capabilities for Data for Research and Discoverability right? Are there any missing or additional needed?**

Question 34: **Are there any international research infrastructure collaborations or emerging projects that Australia should engage in over the next ten years and beyond?**

Question 35: **Is there anything else that needs to be included or considered in the 2016 Roadmap for the Data for Research and Discoverability capability area?**

Attachment A – Making a Submission

Please note the following key information about making a submission to the 2016 National Research Infrastructure Capability Issues Paper.

Who can make a submission?

Anyone is welcome to comment and make submissions on the 2016 National Research Infrastructure Capability Issues Paper.

How will submissions be used?

Every submission received will be reviewed and considered as part of the 2016 National Research Infrastructure Roadmap development process.

Will submissions be publicly available?

Written submissions will be publicly available on the Department of Education and Training's website and will be able to be read by others, unless you have requested confidentiality status.

Why do I have to register to make a submission or comment online?

The information provided in the registration form will help us analyse the responses and help us know which issues are of concern to stakeholders in national research infrastructure.

Can I provide a submission in another format?

No, for accessibility reasons only the word template available from the Department of Education and Training's website should be used and an example copy has been provided. This will also ensure the most effective consideration of the issues you raise in your submissions.

How do I make a submission?

- Download and complete the submission form – available at: https://www.education.gov.au/2016-national-research-infrastructure-roadmap. Please note the following:
    - Format: Word
    - Font: no smaller than size 11 font
    - Actual submission: a maximum of 20 pages
    - Attachments: a maximum of 50 pages
- Email your submission plus attachments to RoadmapSubmissions@education.gov.au

Submissions and comments will close at **5.00pm (AEST) 9 September 2016**.

Do I have to respond to all of the questions in the submission form for my views to be heard?

No, you do not have to answer all the questions. However, please follow the overall template format by providing responses to the questions in the template rather than in free text format.

Submission Template

2016 National Research Infrastructure Roadmap Capability Issues Paper

Submission No: *(to be completed by Departmental staff)*	
Name	
Title/role	
Organisation	
Preferred contact phone number	
Preferred email	
Would you like your submission to remain confidential, i.e. not published on the website?	**YES/NO**

Question 1: Are there other capability areas that should be considered?

Question 2: Are these governance characteristics appropriate and are there other factors that should be considered for optimal governance for national research infrastructure.

Question 3: Should national research infrastructure investment assist with access to international facilities?

Question 4: What are the conditions or scenarios where access to international facilities should be prioritised over developing national facilities?

Question 5: Should research workforce skills be considered a research infrastructure issue?

Question 6: How can national research infrastructure assist in training and skills development?

Question 7: What responsibility should research institutions have in supporting the development of infrastructure ready researchers and technical specialists?

Question 8: What principles should be applied for access to national research infrastructure, and are there situations when these should not apply?

Question 9: What should the criteria and funding arrangements for defunding or decommissioning look like?

Question 10: What financing models should the Government consider to support investment in national research infrastructure?

Question 11: When should capabilities be expected to address standard and accreditation requirements?

Question 12: Are there international or global models that represent best practice for national research infrastructure that could be considered?

Question 13: In considering whole of life investment including decommissioning or defunding for national research infrastructure are there examples domestic or international that should be examined?

Question 14: Are there alternative financing options, including international models that the Government could consider to support investment in national research infrastructure?

Health and Medical Sciences

Question 15: Are the identified emerging directions and research infrastructure capabilities for Health and Medical Sciences right? Are there any missing or additional needed?

Question 16: Are there any international research infrastructure collaborations or emerging projects that Australia should engage in over the next ten years and beyond?

Question 17: Is there anything else that needs to be included or considered in the 2016 Roadmap for the Health and Medical Sciences capability area?

Environment and Natural Resource Management

Question 18: Are the identified emerging directions and research infrastructure capabilities for Environment and Natural Resource Management right? Are there any missing or additional needed?

Question 19: Are there any international research infrastructure collaborations or emerging projects that Australia should engage in over the next ten years and beyond?

Question 20: Is there anything else that needs to be included or considered in the 2016 Roadmap for the Environment and Natural Resource Management capability area?

Advanced Physics, Chemistry, Mathematics and Materials

Question 21: Are the identified emerging directions and research infrastructure capabilities for Advanced Physics, Chemistry, Mathematics and Materials right? Are there any missing or additional needed?

Question 22: Are there any international research infrastructure collaborations or emerging projects that Australia should engage in over the next ten years and beyond?

Question 23: Is there anything else that needs to be included or considered in the 2016 Roadmap for the Advanced Physics, Chemistry, Mathematics and Materials capability area?

Understanding Cultures and Communities

Question 24: Are the identified emerging directions and research infrastructure capabilities for Understanding Cultures and Communities right? Are there any missing or additional needed?

Question 25: Are there any international research infrastructure collaborations or emerging projects that Australia should engage in over the next ten years and beyond?

Question 26: Is there anything else that needs to be included or considered in the 2016 Roadmap for the Understanding Cultures and Communities capability area?

National Security

Question 27: Are the identified emerging directions and research infrastructure capabilities for National Security right? Are there any missing or additional needed?

Question 28: Are there any international research infrastructure collaborations or emerging projects that Australia should engage in over the next ten years and beyond?

Question 29: Is there anything else that needs to be included or considered in the 2016 Roadmap for the National Security capability area?

Underpinning Research Infrastructure

Question 30: Are the identified emerging directions and research infrastructure capabilities for Underpinning Research Infrastructure right? Are there any missing or additional needed?

Question 31: Are there any international research infrastructure collaborations or emerging projects that Australia should engage in over the next ten years and beyond?

Question 32: Is there anything else that needs to be included or considered in the 2016 Roadmap for the Underpinning Research Infrastructure capability area?

Data for Research and Discoverability

Question 33 Are the identified emerging directions and research infrastructure capabilities for Data for Research and Discoverability right? Are there any missing or additional needed?

Question 34: Are there any international research infrastructure collaborations or emerging projects that Australia should engage in over the next ten years and beyond?

Question 35: Is there anything else that needs to be included or considered in the 2016 Roadmap for the Data for Research and Discoverability capability area?

Other comments

If you believe that there are issues not addressed in this Issues Paper or the associated questions, please provide your comments under this heading noting the overall 20 page limit of submissions.

Attachment B – 2016 National Research Infrastructure Roadmap Expert Working Group and Capability Experts

Expert Working Group

Dr Alan Finkel AO, Chief Scientist (Chairman)

Professor Aidan Byrne, Chief Executive Officer, Australian Research Council (ex-officio)

Professor Edwina Cornish AO, Provost and Senior Vice-President, Monash University

Dr Andrew Cuthbertson, Chief Scientific Officer and R&D Director, CSL Ltd

Professor Sandra Harding, Vice Chancellor and President, James Cook University

Mrs Rosie Hicks, Chief Executive Officer, Australian National Fabrication Facility Ltd

Professor Anne Kelso AO, Chief Executive Officer, NHMRC (ex-officio)

Professor Suzanne Miller, Chief Executive Officer and Director, Queensland Museum

Dr Adrian (Adi) Paterson, Chief Executive Officer, ANSTO

Professor Andy Pitman, Director, ARC Centre of Excellence for Climate System Science

Taskforce

The Expert Working Group is supported by the National Research Infrastructure Roadmap Taskforce. The Whole of Government Taskforce is based in the Department of Education and Training and includes experts from the Department of Industry, Innovation and Science, the Department of the Environment and Energy, and the Department of Health.

Further information on the EWG and the Roadmap terms of reference are available at https://www.education.gov.au/2016-national-research-infrastructure-roadmap

Capability Experts

Em Prof Mary Barton, Emeritus Professor of School of Pharmacy and Medical Sciences, University of South Australia

Dr Helen Cleugh, Science Director, Oceans and Atmosphere Flagship, CSIRO

Mr Alec Coles OBE, CEO, Western Australian Museum

Dr Jackie Craig, Chief, Cyber and Electronic Warfare Division, Defence Science and Technology Group

Dr Joanne Daly, Fellow, National Research Collections and Informatics, CSIRO

Dr Cathy Foley, Chief, Division of Materials Science and Engineering, CSIRO

A/Prof Peter Gibbs, Laboratory Head, Systems Biology and Personalised Medicine, Walter and Eliza Hall Institute of Medical Research

Prof Peter Gray, Research Leader, Mammalian Cell Lines and Stem Cell Bioprocesses, University of Queensland

Mr John Gunn, CEO, Australian Institute of Marine Science

Ms Cathrine Harboe-Ree, University Librarian, Monash University

Prof Mark Hutchinson, Director, Centre for Nanoscale Biophotonics, University of Adelaide

Prof Sunil Lakhani, Head, Academic Discipline of Molecular and Cellular Pathology, University of Queensland

Dr David Mitchell, CEO, Australian Centre for Plant Functional Genomics

Prof Robyn Owens, Deputy Vice-Chancellor (Research), University of Western Australia

Prof Bob Pressey, Chief Investigator, ARC Centre for Excellence for Coral Reef Studies, James Cook University

Prof Sally Redman AO, Chief Executive Officer, Sax Institute

Prof Lynette Russell, Director, Monash Indigenous Centre, Monash University

Prof Matthew Sanders, Director, Parenting and Family Support Centre, University of Queensland

Prof Timothy Senden, School Director, Research School of Physics and Engineering, Australian National University

Attachment C – Mapping the research infrastructure capability focus areas against the National Science and Research Priorities

Focus Areas	National Science and Research Priorities								
National Research Infrastructure Capabilities	Food	Soil and Water	Transport	Cyber Security	Energy	Resources	Advanced Manufacturing	Environmental Change	Health
Health and Medical Science									✓
Environment and Natural Resource Management	✓	✓				✓		✓	
Advanced Physics, Chemistry, Mathematics and Materials					✓		✓		
Understanding Cultures and Communities			✓						
National Security				✓					
Underpinning Research Infrastructure Needs	✓	✓	✓	✓	✓	✓	✓	✓	✓
Data for Research and Discoverability	✓	✓	✓	✓	✓	✓	✓	✓	✓